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## ROYAL ASTRONOMICAL SOCIETY OF CANADA

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VOL. XVIII JUNE—JULY No. 6

## THE APPLICATIONS OF MODERN PHYSICS TO ASTRONOMY

(*Continued from last issue*)

### *Eddington's Theory of Stellar Structure*

In Eddington's theory* this pressure due to radiation is taken into account. In this case

$$P_g = \beta P$$

and

$$P_r = (1-\beta)P,$$

where $P$ = total pressure, $P_g$ = gravitational pressure, $P_r$ = radiation pressure.

According to the gas laws

$$P_g = R\frac{\rho}{m}T,$$

whence

$$T = \beta \frac{m}{R}\cdot\frac{P}{\rho}$$

$$= \beta \frac{m}{R}\cdot\frac{x}{y}\cdot\frac{GM}{2a},$$

or

$$\beta = \frac{2ayR}{GMmx}T,$$

*Reference may be made to: A. S. Eddington, "On the Radiative Equilibrium of the Stars", *Monthly Notices*, vol. 77, p. 16 and p. 596, 1916-17; and "On the, Conditions in the Interior of a Star", *Astroph. Journal*, vol. 48, p. 205, 1918. Also, H. N. Russell and D. L. Webster, "Note on the Masses of the Stars" *Monthly Notices*, vol. 82, p. 181, 1921-22.—H.F.B.

and $$\beta^4 = \frac{16a^4y^4R^4}{G^4M^4m^4x^4}T^4.$$

Also we have $$P_r = (1-\beta)P = 1/3\, aT^4.$$

Therefore $$\frac{1-\beta}{\beta^4} = \frac{aG^4M^4m^4x^4}{48a^4y^4R^4xP_o},$$

which becomes, on substituting the value for $P_o$,

$$\frac{1-\beta}{\beta^4} = \frac{\pi}{18}\cdot\frac{aG^3}{R^4}\cdot m^4M^2\cdot\frac{x^3}{y^4}.$$

On substituting the values for $a$, $G$ . and $R$, thus becomes

$$\frac{1-\beta}{\beta^4} = 8.2\times10^{-69}\, m^4M^2\,\frac{x^3}{y^4}.$$

In the case of a sphere $\frac{x^3}{y^4} \doteqdot 1$.

For the sun the mean molecular weight $m$, is about 2.8 so that in the case of a star we should be able to assume that

$$m = 2 \text{ at least.}$$

On these assumptions, for a sphere whose mass $M = 2\times10^{33}$,

$$(1-\beta)/\beta^4 \doteqdot \tfrac{1}{2},$$

whence $$\beta \doteqdot 4/5.$$

Thus, for this sphere,

$$P_r = (1-4/5)P = 1/5\, P,$$

a quantity which certainly may not be neglected.

We know that the rate of change of the pressure $P$, at a point with its distance $r$ from the centre, is

$$dP/dr = -\rho g;$$

and that the corresponding rate of change of the radiation pressure is $$dP_r/dr = -c\rho J,$$

where $c$ = mass opacity, that is, the opacity of a column of matter of 1 sq. cm. area and containing one gram,

$\rho$ = density,

$J$ = amount of heat per square centimeter,

$g$ = gravitational attraction at the point.

From these two equations we have

$$dP_r/dP = cJ/g.$$

Suppose now that $M'$ is the mass of that portion of the star which is nearer to the centre than the point considered.

Then $g = GM'/r^2$

and $J = E'/4\pi r^2$

where $E'$ = total amount of energy emitted from the inner sphere. On substituting these values for $g$ and $J$, we have

$$dP_r/dP = cE'/4\pi GM'.$$

Also, since the star has existed for some time, $E'$ will also be the average rate of production of heat.

Let $\eta$ be the average rate of production of heat per gram. Probably as we go toward the centre of the star $\eta$ will increase, while $c$ should become smaller, since at higher temperatures the radiation produced will have a smaller wave length and consequently a higher penetrating power. Thus we cannot say whether the product $c\eta$ becomes larger or smaller and so, for the best value, we may consider that it is constant,

Hence we have

$$dP_r/dP = (c\eta)/(4\pi G).$$

If $c\eta$ is constant we have, on integration,

$$P_r/P = (c\eta)/(4\pi G) = 1-\beta.$$

This shows that the radiation pressure inside a star is always a constant fraction of the total pressure.

Now, since $1-\beta$ is constant,

$$(1-\beta)\beta^4 = 8.2\times 10^{-69}\times m^4M^2x^3/y^4 = \text{constant};$$

and therefore

$$x^3/y^4 = \text{constant},$$

Now $P = xP_o$, and $\rho = y\rho_o$.

Therefore $P^3/\rho^4 = (x^3P_o^3)/(y^4\rho_o^4) = \text{constant}$ for any star, and consequently the cube of the pressure is proportional to the fourth power of the density.

For $x$ and $y$ the following values have been obtained

$$x = 91,\ y = 54,$$

whence $x^3/y^4 = 1/11.$

Therefore, finally,

$$(1-\beta)/\beta^4 = 4.7\times 10^{-68} M^2;$$

or, using the mass of the sun as the unit of mass,

$$(1-\beta)/\beta^4 = 0.19(M/M_s)^2$$

where $M$ = mass of star, and $Ms$ = mass of sun.

We have also that, at the surface

$$E' = \eta M = (1-\beta)4\pi GM/c.$$

From this we see that *the brightness of a star is proportional to its mass, proportional to* $(1-\beta)$, *or to the radiation pressure, and inversely proportional to the opacity.* Thus we see that, for a star to shine, the quantity $(1-\beta)$ must be appreciable. If we evaluate $1-\beta$ for spheres whose masses are

$$10^0,\ 10^1,\ 10^2,\ 10^3 \ldots \text{etc.}$$

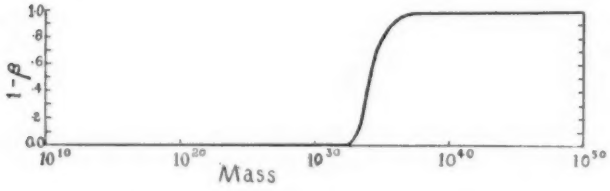



Fig. 14. Diagram showing relation between mass and radiation

we obtain values as shown in the diagram. For values of $M$ less than $10^{30}$ the value of $1-\beta$ is practically zero. At $M=10^{30}$ the value of $1-\beta$ begins to rise, reaching a value of $\frac{1}{2}$ at about $M=10^{33}$, and being near the maximum at $M=10^{36}$, while before $M=10^{40}$ the radiation pressure equals the total pressure. Thus we see that, for a mass less than $10^{33}$ the radiation pressure is not sufficient to cause it to shine as a star, while, for masses greater than $10^{36}$ the radiation pressure is doing all the work, and the star, consequently, is unstable and will break up. *In general, then, little masses do not shine, large masses do not last, and only intermediate masses, corresponding to the steep part of the curve, endure.* It has been found, moreover, that the actual masses agree with the masses required by this theory.

*On what does the Mass of a Star Depend?*

Let us now consider the factors on which the mass of a star depends. We have already developed the equation

$$(1-\beta)/\beta^4 = (\pi a G^3 x^3 m^4 M^2)/(18 R^4 y^4).$$

This equation can be further simplified. For, if

$N$ = number of molecules per gram molecule,
$\mu$ = actual weight of a molecule,
$R$ = gas constant,
$k$ = gas constant for one molecule,

then

$$R = Nk,\ m = N\mu.$$

We have, also, according to Planck's theory,

$$a = (8\pi^5 k^4)/(15 c^3 h^3),$$

where $c$ = velocity of light,
$h$ = quantum constant.

On substituting these values in the original equation we have

$$(1-\beta)/\beta^4 = (4\pi^6 G^3 \mu^4 M^2 x^3)/(135 c^3 h^3 y^4).$$

This equation can be still further simplified if we introduce the theory of "ultimate rational constants". According to this theory

$$c^3 h^3 = 2^{15}\pi^{11} e^6/15$$

where $e$ is the charge on one electron.

On substituting this value in our equation we have

$$(1-\beta)/\beta^4 = (1/(9\times 2^{13}\times \pi^5))\ (x^3/y^4)\ (M/\mu)^2\ (G\mu^2/e^2)^3.$$

According to Eddington's theory the quantity $x^3/y^4$ is constant throughout the star and is equal to 0.0918. On substituting this value, together with that of $\pi$, in the equation we have

$$(1-\beta)/\beta^4 = 4.07\times 10^{-9}(M/\mu)^2(G\mu^2/e^2)^3.$$

In this equation the quantity $(M/\mu)$ is simply the number of molecules in the star while the quantity $(G\mu^2/e^2)$ is the ratio of the gravitational attraction of two molecules at a given distance to the electrical repulsion between two electrons the same distance apart.

Now let $R$ = radius of the star,

$r$ = radius of the sphere occupied, on the average, by an atom.

Then the number of atoms in the star,

$$M/\mu = R^3/r^3.$$

Substituting this value in the equation we have

$$(1-\beta)/\beta^4 = 4.07 \times 10^{-9}(R^3/r^3)^2(G\mu^2/e^2)^3,$$

or

$$R/r = 25(e/(\mu\sqrt{G}))\ ((1-\beta)/\beta^4)^{1/6}.$$

On the steep part of the curve between $1-\beta$ and the mass the values of $(1-\beta)/\beta^4$ range from .01 to 100, and therefore $((1-\beta)/\beta^4)^{1/6}$ has values between .5 and 2. On substituting these values in the above equation we find that the limiting values are

$$R/r = 12e/(\mu\sqrt{G}),$$

and

$$R/r = 50e/(\mu\sqrt{G}).$$

Now the average distance between atoms will be slightly less than $2r$, so that the values of the ratio $(R/2r)$ are certainly between

$$R/2r = 5e/(\mu\sqrt{G}),$$

and

$$R/2r = 30e/(\mu\sqrt{G}).$$

Therefore, in any mass of gas, such as a giant star, the ratio of the radius $R$ to the average distance between the atoms is from 5 to 30 times as great as the ratio of the electrostatic attraction between electrons to the gravitational attraction between atoms at the same distance apart.

Hence we see that the reason why stars of the giant class are so big is because the attractive power of electrons is enormously greater than the gravitational power of atoms.

By this theory, then, we can say that the properties of the giant stars do not depend on the properties of matter or atoms, but solely on the fundamental physical constants such as the charge on the electron and the force of gravitation.

For dwarf stars a modifying factor must be included in Jeans's equation. Instead of writing, as before

$$T = mp/(R\rho),$$

we now write

$$T = mp/(BR\rho),$$

where $B$ is a factor which is greater than 1.

For $B=1$, we have the case of the giant stars in which the matter is

a gas

and for $B>1$, we have the case of the dwarf stars in which the matter is not exactly a gas.

We must also modify the equation

$$pv=RT$$

by writing $$p(v-v_o)=RT,$$

where $v_o$ = the volume occupied by the gas at absolute zero.

From these two equations we have

$$B=\rho_o/(\rho_o-\rho),$$

where $\rho_o$ = density at absolute zero,

$\rho$ = density at temperature of the star.

Using this value of $B$ and proceeding as in the case of giant stars, we are able to determine the factors governing dwarf stars.

Thus we see that, according to Eddington's theory, the properties of the giant stars are most beautifully explained, using only the fundamental properties of gravitation and electricity, while the properties of dwarf stars depend also on the sizes of atoms.

*What becomes of the Energy Radiated?*

We have been able to determine that, each year, the sun gives off 1.5 calories per gram. This cannot be produced by chemical combination since, under the most favourable circumstances the supply of heat could only last for a thousand or so years. Helmholtz pointed out that the contraction of the sun would supply enough heat, the contraction necessary being imperceptible over a period of 1,000 years. But on this theory the whole amount of heat which could be produced would be equivalent to 15,000,000 years' supply, but of this there would be available for radiation an amount sufficient only for less than ten million years. Thus in a few million years the whole supply of heat from gravitational energy would be used up.

Within the last few years we have obtained a method of measuring long periods of time based on radio-activity. This method is comparable to the measurement of the greater stellar distances and might be aptly described as "parallax of time". The atom of a radio-active substance has the same constitution as any other atom and consists of a nucleus around which a number of electrons revolve in orbits. In ordinary substances, however, the nuclei are

stable while in a radio-active substance the nuclei are not absolutely stable but, at regular periods on the average, give off part of the nucleus to form a new atom. For uranium the average half-life or period required until half the total amount which can be radiated is gone, is 5,000,000 years. As more and more of the nucleus is radiated the element changes its character, ending up as a kind of lead which has no tendency to break down and whose properties are identical with those of lead except that its atomic weight is 206 instead of 207.1. This is called an *isotope*.

### *Existence of Life on the Earth*

Now both uranium minerals and lead are found in crystals which are believed to have crystallized from the original igneous mass which formed the earth, the lead being that whose atomic weight is 206. Consequently the uranium-lead ratio gives us a measure of the time taken for the lead to form. Minerals from the middle pre-Cambrian age all indicate that their age is about 1,200,000,000 years. Now the Cambrian rocks are fossiliferous, the type of life represented being far from primitive. This is shown by the fact that, of the types of life now existing, three-quarters appear in these rocks. Consequently we can say that evolution appears to have done more than half its work before the Cambrian era, and therefore life must have existed on the earth for a period of the order of a billion years.

### *Age of the Sun and the Source of its Energy*

This throws some light on the age of the sun. If its stellar magnitude were to fall one-half a magnitude, in which case its brightness would be two-thirds of its present value, a universal ice age would be the result; and if it were to rise one magnitude, and the brightness become $2\frac{1}{2}$ times as great as now, the temperature of the earth would rise to the boiling point. So that, if the sun's magnitude should increase by one magnitude and remain so even for one year all the seas would boil away and all life would be annihilated, while if it decreased one-half magnitude for one century all life would be frozen. Thus, during the period life has been on the earth the sun's magnitude must have remained within half a magnitude of its present value, which is about $-26.7$. Thus the sun has been giving off energy at about its present rate

over a period 1,000 times as long as would be possible if gravitational energy were the only source of the sun's heat. This shows us that the life of the sun must have been enormous, for if it had been of F type its magnitude would be 2 greater than at present. Consequently the whole life of the earth—a billion years—was the time required for the sun to change from type F5 to G. We can certainly assume, then, that the sun, during its life, has given off a thousand times the total possible energy due to gravitation. This energy must have been stored in a small space, and the only probable place is the nucleus itself. This is in direct agreement with the theory of radio-activity, since in this phenomenon the nucleus gives off energy. Thus we are driven to the idea that in the nucleus of the atom is a great store of energy which is given off from time to time under favourable conditions. This giving off of energy, however, is not taking place on the earth, and consequently we must assume that the process by which the nucleus liberates energy operates only at high temperatures. That is, that the rate of production of energy is too small to be taken into account until a temperature of millions of degrees is reached, when the process operates uniformly.

According to this theory, at first glance, as the temperature increases more energy is liberated by the nuclei. This, in turn, would cause a still further increase in temperature until, finally, a monstrous explosion would take place. We know that nothing of this nature takes place, however. For, as heat is added to the star from the nuclei of the atoms, the star will expand and as a result will become cooler. And as it becomes cooler the "unknown source" in the atoms ceases to act and the star will contract again. Thus there is in the star an automatic self-adjustment, which regulates the amount of heat produced, to prevent any catastrophe and to enable the star to radiate heat at its regular uniform rate. And, as the star slowly cools, the rate of emission adjusts itself to the rate of supply. In this way we can account for the duration of practically constant rates of radiation for exceedingly long periods of time, assuming only the existence of an unknown source of energy which operates only at high temperatures, and which gives more heat the higher the temperature becomes.

### *The Source of Energy in the Atom*

We have now to consider what this "unknown source" of energy can be. And, since this source is undoubtedly in the atom, we must study the atom and determine its properties. If positively charged particles—ionized atoms—are passed along a tube at high speed, and are subjected to the action of a combined magnetic and electrostatic field, they will be deviated from their original path by an amount which depends on the value of $e/m$ and which can be calculated. Now the charge on an electron is constant, and so, if an atom is ionized, *i.e.*, has lost one electron, it will bear a charge of $+1$. Thus, if atoms of a substance are deflected through two different angles, it means that there is a difference in the masses of the atoms. Moreover, for any given deflection, knowing the strengths of the magnetic and electrostatic fields, the mass of the atom can be calculated.

For many substances, such as sodium, carbon, oxygen and nitrogen, the atoms are all alike and, therefore, are deflected through only one angle under constant conditions. In other cases, however, under the same constant conditions, the atoms are deflected, some through one angle and some through another. An example of this is the case of the element chlorine, for which $m$ is 35.4 as determined by ordinary methods. When this gas is examined in the above method, however, it is found to be deflected by amounts equivalent to $m=35$ and to $m=37$, no deflection being found for $m=35.4$. Thus chlorine is composed of two substances which are inseparable by chemical and physical means, and which differ only in the weight of the nucleus. Such substances are known as isotopes. A large number of such experiments show that the weights of all atoms except hydrogen are exact multiples of whole numbers.

### *Mass and Energy Interconvertible*

Now, the hydrogen atom, which is the lightest atom, has a weight 1.008 and is not composed of two isotopes, and the next heavier atom, that of helium, has a weight 4.00. If, then, by some means we were to take four grams of hydrogen atoms and turn them into helium atoms, we should have 0.032 gram left over. Moreover, there is no atom having this atomic weight, and, con-

sequently, this matter could not form a separate atom. Now, Einstein, in his general theory of relativity, says that mass and energy are interconvertible, the relation between them being

$$Mc^2 = E,$$

where $M$ is the mass in grams, $c$ the velocity of light in cms. per sec., and $E$ is the energy in ergs. Thus one gram of matter could be converted into $9 \times 10^{20}$ ergs of energy. Thus, for every gram of hydrogen that is changed into helium, 0.008 gram mass is lost and $0.008 \times 9 \times 10^{20}$ ergs, or approximately $7 \times 10^{18}$ ergs, of energy are produced. Now 1 calorie is equivalent to $4.2 \times 10^{7}$ ergs and hence the loss of 0.008 gram mass produces approximately $1.5 \times 10^{11}$ calories of heat.

If, now, we suppose that in the sun the hydrogen atoms in some way are taken apart and built up into helium atoms, the energy thus produced would be sufficient to maintain the present radiation of the sun for 100 billion years. This seems to be of the right order of magnitude. And if it is necessary to provide for still more energy, we might extend our theory somewhat, so as to include the formation of uranium from hydrogen in the same manner. In this case we should have both energy due to loss of mass and also to radio-activity.

This theory is, of course, purely speculative, but it is certainly plausible and seems to be somewhat justifiable.

## VII. Some Special Problems

### *Clouds of Metallic Vapour*

There remain certain problems in astronomy which must be discussed. One such problem is that of the hot stars. In the case of the hot stars—those of types B and O—all the lines are wide and fuzzy except the lines of ultimate ionized calcium and, sometimes, those of sodium, which are quite sharp. Moreover, in the case of double stars of these types, all the lines shift due to velocity, except these lines. These sharp lines, moreover, indicate a velocity the same for both Ca and Na, but different from that of the star. This evidence, then, indicates the presence of clouds of metallic vapour associated with these stars, but, since it is not affected by their motion, it must be remote from them. There is not much

difficulty in understanding this for sodium, since the metal will absorb light, producing the D lines, at low temperatures and, therefore, when subject to radiation pressure. In the case of calcium it is somewhat more difficult to understand. The explanation, then, seems to be that, around the star at a distance of perhaps light-weeks or months, there is present a layer of atoms, driven off from the star by radiation pressure; and this layer need not contain many atoms since the same effect is produced in the laboratory by 1/100 inch of metallic vapour.

### *The Problem of the Cepheid Variable*

The Cepheid variables, also, provide an interesting problem. These variables are so called from δ Cephei, which is the brightest and most conspicuous of the type, and they are used in parallax determinations. The light from these stars varies with beautiful regularity, the light curve of some resembling a sine curve, while that of others is somewhat similar to a sine curve except that the rise in brightness is comparatively rapid while the fall is somewhat slower. Both these types of light curve are shown in Figs. 2 and 3. These stars may be divided into two groups according to their periods. In the first group are those having long periods, there being a few with periods of 100 days, a maximum number having seven day periods and a minimum with periods from two to three days. The second group is composed of those of very short periods. In this group are a few with a period of about 18 hours, a maximum number with 12-hour periods and a few with still shorter periods. These stars are distributed widely throughout the sky, hundreds being found in the clusters, hundreds being isolated stars, and many being found in the Magellanic Clouds.

Until quite recently these Cepheid variables were one of the greatest puzzles to astronomers. A very great deal was known about these stars, but this knowledge could not be co-related. Probably, had less been known, there would not have been any great uncertainty.

The brightness of these stars does not change beyond two magnitudes. As they become fainter they become redder and also change their spectral type to one lower in the sequence, the change being about one type. Thus these stars vary in brightness,

colour and spectral type, all of these properties becoming maximum or minimum about the same time. Along with these changes is also a change in radial velocity. When the star is brightest the spectral lines are shifted to the violet, showing that the star is approaching us, while when the star is faintest the opposite is the case, the change in velocity, however, being small. These stars are, moreover, giant stars and are about 1,000 times as bright as our sun.

If we plot brightness against log. period we find that the resulting graph (Fig. 4) is a straight line except for a small part where the curve becomes more and more nearly parallel to the log. period axis. We can say that a determination of the brightness from the period from this curve is 85 per cent. satisfactory.

### *The Pulsation Theory*

To account for the behaviour of these stars the "Pulsation Theory" has been advanced. According to this, these stars expand and contract—shrink inward, and then expand outward during the period, always remaining spherical. Mere cooling will not account for this, and, therefore, there must be an oscillation from heat energy to another form of energy and back again. This other form of energy is probably gravitational energy. As the star contracts its temperature increases, it becomes whiter in colour, and is of an earlier spectral type, as is expected. Moreover, as it contracts its surface moves away from us, and as it expands its surface moves towards us, producing the shift of the spectral lines which has been observed. We can, therefore, on this theory, account for the change in colour, brightness and spectral type, and also for the shift of the spectral lines.

Now we have obtained the sizes of some of these stars, and so the amount of shift of the surface, in order for our theory to hold, must be much less than the diameter of the star. The extreme shift has been found to be 14 per cent. of the diameter, while the average shift is about 8 per cent. These values, then, are quite in keeping with the theory. We now wish to know what is the change in temperature. According to Eddington, for a 7 per cent. change in diameter, an 8 per cent. change in temperature would be satisfactory. This is in agreement with the actual values.

From the period and size of the star we are able to calculate

the density. For those of short periods, the density is one half that of water, which is quite reasonable for a star of type A. In the case of those of medium period and of long period the densities are also reasonable for F and K type stars respectively.

We are also able to calculate the masses of these stars, and we find that, as in the case of the densities, the masses are quite in keeping with stars of these spectral types.

According to the above reasoning the star should be hottest when smallest and therefore when the surface has just ceased receding from us. Observation, however, shows that it is hottest when the surface is approaching us. This apparent failure of our theory is easily explained, for, when the star is smallest, the surface is heating at the expense of the centre, and so will be hottest shortly after the centre has reached its maximum temperature. This means that there will be a lag in the temperature and brightness, and so our observations are in agreement with our theory.

We have observed that there are two different types of light curve for these stars (Figs. 2, 3); one indicating an even rise and fall, and the other a rapid rise and slow fall in magnitude. Eddington has shown that, for a small oscillation, the rise and fall will be regular, while, for large oscillations, the rise will be more rapid than the fall.

### *What Keeps the Pulsations from Dying Out?*

We have now to determine what it is that keeps these pulsations from dying out. Since there is a leakage of heat from the hot to the cold parts of the star, the expansion will become less and less and the pulsations would entirely cease within the course of a few thousands of years. That is, the leakage of heat has the same effect on the star as friction. Now, it is unreasonable to suppose that these pulsations commenced within the past few thousand years and so we must look for some agency which will keep the pulsations from dying out.

In our hypothesis of an "unknown source" we provided that it should operate only at high temperatures. Hence a series of impulses would be given from this source, one each time the star contracted and so raised the temperature sufficiently to cause the source to operate. This would cause the pulsations to increase

until some other effect counteracted it. To illustrate the process which goes on, let us consider a ship at sea. If the period of the roll of the ship is 15 seconds and the period of the sea is also 15 seconds the roll will increase. But when the amplitude of the roll exceeds a certain amount the period becomes different from 15 seconds and the roll is automatically checked. It is believed that a similar process to this goes on within the stars, although this has not yet been proved.

There remains yet some difficulty about the shape of the light-curve and the amount of the lag. But we can say that, considering the matters yet to be explained, our theory is about 85 per cent. good.

### *Ionization and the Colour of the Stars*

Another astrophysical problem, the solution to which is based on the modern theory of ionization, is in connection with the colour of the stars. We know that stars of types B and O have spectra of highest excitation while those of type M have spectra of lowest excitation. We saw, too, that a smooth curve is obtained on plotting the colour index of a star against its spectral type (Fig. 12), which means that there is a definite relation between the colour of a star and its spectral type. This, however, is not rigorously true, for the giant stars of any type are redder than the dwarf. For example, a giant K is redder, and therefore colder, than a dwarf K. Now the type of a star, it will be remembered, is determined by the relative intensity of the enhanced and the arc lines, and also by the intensity of the lines of ionized calcium—the *H* and *K* lines. Since the giants have much lower density than the dwarfs, for the same temperature, there will be relatively more ionized atoms in the giant. This is brought about by the fact that, when the density is low, an atom, having once lost an electron, will have greater difficulty in capturing one than it would where the density is high and where, consequently, the atoms are more crowded. Thus, for the same temperature, the giants will exhibit more intense ionized lines than the dwarfs, and so will be of higher spectral type. In other words, giants of the same spectral type will be cooler, and, therefore, redder than dwarfs. Thus the difference in colour between giants and dwarfs supports the theory of ionization.

*Stars becoming Fainter but not Redder*

Another phenomenon, known as Hertzsprung's phenomenon, seems, at first sight, rather puzzling. A comparison of colour index and absolute magnitude shows that, as a star becomes redder and redder, it also becomes fainter and fainter until it reaches the eighth or ninth magnitude. At this point, when the brightness is from 1/10 to 1/20 that of the sun, there is a fairly steep drop in brightness, while, from 1/20 to 1/50 the brightness of the sun, the colour is practically constant. Thus we have stars of about a hundredfold range in brightness with the same colour index and spectrum.

Now the same brightness and colour means that the star has the same brightness per square mile. Now we have stars, one 100 times as bright as the other, whose colour index is the same and whose mass must not be very different. This reasoning gives us the absurd density of 100 times that of water. If, on the other hand, we take the known masses, and have the density as great as is at all reasonable, we are led to the conclusion that the stars have small surface brightness, where our previous reasoning gave the same surface brightness.

Hertzsprung brought forward an ingenious explanation of this phenomenon depending on the difference in physical condition between a giant and a dwarf star. To show this we must go over Eddington's theory. According to this theory we have

$$(1-\beta)/\beta^4 = KM^2,$$

where $\beta$ is the proportion of the radiation pressure to the total pressure $P$.

Also $$T^4/P_g = \big((1-\beta)/\beta^4\big)C,$$

where $P_g$ is the gas pressure and $C$ is a constant.

Therefore, so long as a star is gaseous of low density, the pressure is constant for constant temperature. This means that, as a giant star goes through its history, according to Eddington the pressure is always the same at points of the same temperature. But, when a star gets over its maximum temperature we must write our equation

$$(1-\beta)/\beta^4 = KM^2/B,$$

where $B$ is a constant greater than 1.

This means that the value of the radiation pressure decreases as a star begins to reach the dwarf stage. That is, for the same total pressure, the radiation pressure is less and, as a result, for the same gas pressure, the temperature is less. Thus, where the pressure is the same the temperature is much lower in a dwarf than in a giant star.

Finally, due to this fall in temperature, somewhere in the atmosphere of the star, some substance will condense into liquid, forming real clouds. Now clouds are quite opaque and so little heat will pass through them and their outer surface will cool and become dark. Being opaque these clouds will, as it were, dam up the flow of heat and the temperature inside will rise, causing the clouds to dissipate. As the heat disappears into space the clouds will tend to form again. If the supply of heat is only 80 per cent. of what would be radiated at the temperature at which clouds form, clouds will form over about 20 per cent. of the surface, leaving 80 per cent. clear; while, if only 20 per cent. of the heat is available for radiation, 80 per cent. of the atmosphere will be clouded. Thus there is a state of equilibrium maintained between the supply of heat for radiation and the amount of cloudiness. Now all the light from the clear spaces will be from a surface of the same temperature whether the surface is 80 per cent. clear or only 20 per cent. Thus the star becomes fainter without becoming redder.

A check on this theory is provided by the fact that the temperature of these stars has been found to be about 3,000°. At this temperature carbon and tungsten will form clouds, and so our theory is tenable.

### *The Problem of White Dwarfs*

A problem which is still puzzling astronomers is that of the white dwarf stars. The star Omicron Eridani has a companion which is a double star. One of the components is an M type dwarf and the other is of type B9 and is therefore quite hot and white. This star, however, is only 1/200 as bright as the sun and has only 1/3 of the sun's mass, and is, therefore, certainly a white dwarf—a star which is not accounted for in the theory of stellar evolution that has been presented.

If we assume the density of this star to be 10 times that of the sun, which is the greatest reasonable density we can give it, for the same surface brightness it should be 1/10 as bright as the sun, whereas it is actually 1/200 as bright. Reasoning differently, since it is 1/200 as bright as the sun its surface brightness should be 1/20 that of the sun. This is hardly consistent with it being a much whiter star than the sun is.

Hertzsprung's phenomenon is the only one which gives any hope of solution of this problem. The possible solution, then, is a very extreme case of cloudiness. This hardly seems probable, but it is, at least, conceivable.

If these stars were rare we might perhaps treat them as an exception, but they are not as rare as might appear. It is true that we know of only three of them. These three, however, are all within a distance of twenty light-years, and so they must be fairly common in the sidereal universe.

Until these are explained our theory of stellar evolution and constitution will remain incomplete.

### *The Problem of the Long-period Variables*

The problem of the long-period variables must also be discussed. A typical star of this type is o Ceti, or Mira. This star, which might be termed a variable variable, has a period of about eleven months and a fairly, but not exactly, regular light-curve. At its faintest this star is of the 9.5 magnitude, and, when brightest, may have a magnitude of 3 or 3.5. It has, therefore, about a thousand-fold range in brightness.

There are large numbers of these variables, their average variation in brightness being about five magnitudes and their periods ranging from about ½ to 2 years, the average period being about one year. Each of these stars is quite red, most of them being of type M, while some are of types N, R and S. Belonging to these classes, their spectra all exhibit bands, and the stars are therefore cool enough to permit the formation of compounds. They have an average absolute magnitude 0, and are, therefore, comparable in every way to the other giant stars. These long-period variables are, then, giant stars which become faint. At the times of maximum brightness the spectra of these stars exhibit

the bright lines of hydrogen, while, at the times of minimum brightness, there are faint arc lines of the metals present. The radial velocity of these stars, too, is subject to a small variation with a phase opposite to that of the light. That is, the stars approach us when they are faintest.

We are far from having a complete theory in explanation of these stars. Possibly there is some sort of pulsation taking place. It is certain, however, that if this pulsation exists it is not of the same sort that exists in the Cepheids, since the period is not always of the same length and the maxima are not of the same brightness.

We know that, as we pass through the spectral sequence from B to M, the ratio of heat to light becomes greater, so that, in a red star there is much more heat in proportion to the light. In the case of these long-period variables, this ratio is even greater than for the ordinary stars of this class, being, at minimum brightness of the order of 1000:1. At maximum the light effect is, of course, greater, while the heat effect, measured by the thermopile, does not increase in proportion and so the heat-light ratio is at its minimum value. This indicates a very low temperature at minimum. At this low temperature the spectra of a great number of the familiar lines disappear apparently only leaving the lines of the oxides of metals.

If the temperature is sufficiently low at these minima condensation will occur, producing clouds. As a result the heat flowing outward will be trapped behind the clouds which also cause a great diminution in the brightness of the star. In time this heat will cause the clouds to disappear, when the heat will be given off. This agrees with the radial velocity change. For a star which is storing heat behind clouds will be expanding, giving a motion of approach, while, when it is brightest it will contract and will appear to be receding. This theory is, of course, only speculative, but it is a possible solution of the problem.

### *The Problem of the Novae*

Another problem is presented by the Novae, or new stars. Every few years a star suddenly appears where no naked-eye star existed before. In 1918, Nova Aquilae appeared as a star of the 1 magnitude, the next day it was of the 0 magnitude, after which

it gradually faded out. On the Harvard plates, two days before discovery, it appeared as a star of the 11 magnitude and consequently, in two days, it increased 10 magnitudes in brightness. Similarly, in 1901, Nova Persei, which was ordinarily of the 13 magnitude, increased 100,000-fold in brightness.

These stars, then, are tremendous flare-ups in the heavens, actually catastrophic in their nature. There is a many thousandfold increase in brightness in a short time, after which the brightness gradually diminishes. As the brightness increases the typical dark line spectrum of type B or F is shown, and this indicates a great radial velocity in our direction. Then the typical nova spectrum appears, in which are wide bright bands with dark bands at the edges which are toward the violet, the shift indicating a tremendous velocity of approach of from 1,000 to 1,800 km. per second. Still later the bright bands of the nebulae appear, after which the spectrum becomes that of a typical O-type star.

In the case of Novae a different type of explanation is demanded. These are the most gigantic catastrophes known to science, and, at their brightest, are brighter than any other known stars.

Our theory is that, at the outburst, a shell of gas is blown out, which continues to expand. Consequently there will be wide absorption lines due to absorption by the shell. Now the light from the star passes through that part of the shell which is approaching us fastest, and so the bands will be displaced toward the violet. The bright lines will be produced by those parts of the shell not causing absorption. These parts are moving, some in one direction and some in another, their velocity in the line of sight never exceeding that of the part causing the absorption. Thus there will be a broad bright band to the red of each absorption band and extending on each side of the normal position of the line if there were no velocity effect.

### *The Halo round the Nova*

As seen in the telescope there is a sort of green halo around the star, which steadily expands, becoming larger and larger. If this halo were really the shell we supposed to exist, and we place the slit of the spectroscope across the image of the star, we should obtain the stellar spectrum, and also, due to the shell, a bright

oval around each line in the stellar spectrum. Where there is no radial velocity of the shell, that is at the top and bottom of the image, there should be no displacement. But, as we move from the top or bottom toward the centre we have the image of two parts of the shell, one moving towards and the other away from us, and consequently we should get two lines. And, since the velocity is greater in line with the star we shall have the greatest separation at this point. Thus the shell will give an elliptical line. This is actually obtained and, as a result, the reality of the shell is beyond doubt.

This explains many of the phenomena connected with the Novae, and enables us, from a measure of the angular velocity of the expansion of the shell, knowing the radial velocity from spectroscopic measures, to determine the parallax of the star.

We have proved the existence of this shell, and we must now determine what caused it to be given off in the first place. It is possible that a star, as it moves through space, passes into one of the dark nebulae. As a result, matter would penetrate into the star's atmosphere in a manner similar to that in which meteors enter the atmosphere of the earth. This would cause the surface to become heated and, therefore, brighter. The continuous fall of matter for any appreciable period would cause the surface to become extremely hot so that, finally, the temperature would become sufficiently high to cause the "unknown source" to operate. Since matter is still falling into the star, a pressure will be exerted which will prevent the star from expanding. This will result in more and more heat being liberated by the "unknown source", and finally a tremendous explosion will take place. The result will be that the outer layer of the star will be driven off to form a shell. Since the existence of this shell has been definitely proved, our theory of its formation may be accepted.

## VIII. The Nebulae

### *Clusters and Nebulae*

It has been long since recognized that there are objects in the heavens which are not star like, but which resemble little clouds. To these was given the name Nebulae. Most of these objects, as

larger and better telescopes were built, turned out to be clusters of stars. This is illustrated well in the case of the cluster Praesepe in Cancer. To the naked eye this appears to be a cloud-like patch of luminosity—a nebula—but when the optical aid of even an opera glass is employed, it is seen to be a cluster of separate stars. There are, however, some of these objects which, even under the highest magnification, remain hazy and do not resolve into stars. These, then, are the true nebulae. The two most conspicuous of these nebulae are the Andromeda nebula, which can be detected by the naked eye, and the Orion nebula, which requires but a small telescope to identify.

### *Types of Nebulae*

Nebulae may be divided into two main classes, those which are found in the Milky Way or the Galactic Nebulae, and the others, which are known as Non-galactic Nebulae. The Galactic Nebulae are composed of four types. The first of these types is well illustrated by the nebula near $\theta$ Orionis. This is cloud-like in structure, the luminosity being more or less streaky and having dark patches near it. The light from this type, of which there are a large number in the Milky Way, is conspicuously green, the spectrum exhibiting five of the Balmer series of hydrogen lines, several helium lines and two bright green lines near $H\beta$ together with a faint doublet in the violet. These last mentioned lines, the two bright green ones and the doublet, are present in all gaseous nebulae and have remained unknown up to the present. Moreover, all these lines are quite sharp and distinct, showing us that these nebulae are gaseous. The lines of hydrogen, helium, ionized nitrogen and calcium, and sometimes ionized helium, which are present, are all high excitation lines. Along with these are some few unknown lines, notably those which have been mentioned above.

### *The Green Nebular Lines*

Of the unknown lines the two in the green appear to be together for they are always of the same relative intensity, while the two in the violet are not of the same relative intensity and may therefore be produced differently. These lines appear to be the lines of a permanent gas although they have not been produced in the

laboratory. But, in the periodic classification of the elements there is no room for a new light element which is a permanent gas. Consequently we are forced to believe that these lines are due, not to a new atom, but to a known substance under an unknown type of excitation. The type of nebula just described is known as the *diffuse gaseous* type. The other type of gaseous galactic nebulae is the *planetary* type, of which an example is the Ring Nebula in Lyra. This nebula is composed of a ring with a star in the centre. This central star is hard to see but is quite strong on the photographic plate, indicating that it is extremely blue. It is so blue, in fact, that high temperature cannot be the cause, and consequently there must be some peculiar means of emission of light.

### *Spectrum of the Planetary Nebulae*

When the planetary nebulae are observed by means of the objective prism a gaseous spectrum is shown. The central star or nucleus is extremely strong in the ultra-violet, and is therefore of the O type, the hottest of the hot stars. The images of the ring, however, are not of the same size. The hydrogen lines produce the largest image, the ultra violet lines a large image, the green lines intermediate images, the helium lines small images, while the lines of ionized helium produce still smaller images. Now this order is the order of ionizing potentials, and consequently there must be some sort of influence exerted by the intensely hot nucleus, whose exciting power diminishes as the distance. Thus we may say that the production of the nebular lines requires a relatively small amount of energy.

Still another type of nebula is exemplified by the nebulosity of the Pleiades. In this case the nebula appears to be diffuse but its spectrum is continuous, crossed by dark lines. Thus it is seen that, since the nebular spectrum is the same as the stellar spectrum, the nebula probably shines by reflected light.

### *Dark Nebulae*

The last class of galactic nebula is the *dark* nebula. In this case we have extremely rich star-fields through which appear dark areas,

in some cases narrow, of definite shape and sharply defined. In the case of large dark areas it might be said that no stars were present but, in the case of a small *S*-shaped dark area, it would be most unreasonable to assume the presence of an *S*-shaped tunnel through an immense star cloud and pointed exactly in our direction. Consequently we are led to believe that there is a dark cloud nearer us than the stars and which, therefore, obscures those behind it. In most cases these dark nebulae are not near enough to any star to shine by reflected light. In Sagittarius, however, there are dark nebulae, portions of which are near stars and which are, consequently, illuminated. These therefore shine as ordinary nebulae. We are able, moreover, to obtain a measure of the distance of these nebulae by means of the stars with which they are associated. When we do this we find their distance to be about 500 light years, which is much nearer than the Milky Way.

### *What Kind of Matter in the Dark Nebulae?*

We must now consider the kind of matter which goes to make up these dark nebulae. Up to a certain limit, the finer the particles into which a mass is divided the greater is its absorbing power, on account of the greater effective area which it exposes to incident radiation. This limit is reached where the circumference of the particle is equal to the wave length of light, after which it becomes transparent again. That is, there is a sharp maximum of opacity for particles whose circumference is equal to the wave length of light. Consequently the material forming the cloud must be chiefly in the form of fine dust. We can also say that the particles are in general larger than this limit. For, if they were smaller the nebula would appear blue by reflected light and red by transmitted light, which is not the case. Thus a dark nebula indicates vast opaque clouds of large and small particles of matter, some of which is fine dust. When these clouds are in the vicinity of a star they shine by reflected light, appearing as galactic nebulae of the non-gaseous type. Thus in the case of these galactic nebulae whose spectra are continuous, we should be able to find the attendant star. This has been done for about one hundred of these nebulae. If we were to replace the nebula by a white screen at

the same distance we would find that the screen was just a little brighter than the nebula and that the area of screen visible by reflected light was exactly the same as the area of the nebula. Thus the opaque cloud producing the nebula probably extends for some distance beyond the visible portion.

### *Nebulae Illuminated by Stars*

For gaseous nebulae, too, the star has been found for which this relation holds. Consequently it is reasonable to assume that the nebula is set shining by the star. Why, then, are these nebulae gaseous? When the star is of type $B_1$ or earlier, the nebula is gaseous, while when the star is of type $B_2$ or later the nebula exhibits a continuous spectrum. In general, then, when the star is exceedingly hot the nebula shines as a gas and when it is cooler a continuous spectrum is exhibited. It is believed that the nebulae shine by energy fed into them from the star. We can obtain an idea of the masses of these nebulae from their distance, size and rotation. These masses are from 10 to 50 times that of the sun but their size is so large that the gas is extremely rarefied and each atom is given energy separately, and not by a process of atom acting on atom.

In other words the nebula acts as a collection of separate atoms and not as a continuous medium. There are only two theories which will account for the large amount of energy required. One of these is the absorption of extreme ultra-violet radiations and the other is the collision with high-speed electrons. Now a very hot body, having a temperature from 30 to 50 thousand degrees, both shoots off high-speed electrons and emits strong ultra-violet radiations. In order that a star should satisfy these requirements it must be either of the early B or the O type. Stars found in conjunction with gaseous nebulae are of exactly these types.

The question now arises concerning the absence of the continuous spectrum in gaseous nebulae. This has not yet been satisfactorily explained.

As a result we may say that galactic nebulae shine not of themselves alone but by the influence of stars, either through reflection or excitation.

### *The Orion Nebula*

From the relation holding for nebulae and the stars connected with them, we have said that, in all probability, the cloud of matter extends beyond the luminous part. A conclusive proof that this is so is given by the Orion Nebula. In general this nebula is stationary in space, some parts approaching and some receding from us in a more or less patchy fashion. The nebula, then, is not merely chaotic in form, but turbid, each wisp moving in a different direction at a different speed, the average speed being about 100,000,000 miles per year. Consequently, in a million years portions would be carried from one side across to the other. But the nebula must certainly be more than a million years old, and consequently new material must move in to take the place of that which has moved beyond the edge. Hence the whole neighbourhood must be filled with dark wisps moving turbidly about, some of which drift near the bright star and become luminous by the action of electrons. In general, then, the wisps move in and out, the details of the nebula change, but the nebula is always then composed at different times of different material.

The gaseous galactic nebulae, then, are superficial fluorescences in dark clouds produced by the effect of star radiation.

### *The Spiral Nebulae*

The other great class of nebulae is never found in the plane of the Milky Way, but near the poles, and is therefore called non-galactic. In general these nebulae fall into two groups, the *spiral nebulae* and the *globular nebulae*, although there are also some diffuse and some irregular non-galactic nebulae.

The spiral nebulae consist of two arms which come together in the centre where there is a great condensation, and by their appearance suggest the presence of both luminous and dark matter. The inner portion or condensation in these nebulae gives off yellow light, while the outer portion is extremely rich in violet radiation, being more blue than any star. Consequently this outer portion shines with a different kind of light. The very appearance of the spiral suggests that these nebulae are in motion. Photographs taken at as great intervals as possible enable us to determine the nature of this motion, which is found to be outward and practically

along the arms, the time for a complete revolution being from 60,000 to about 200,000 years. In all known cases the motion of the spiral is outward and generally along the arms, that is, the motion is an outward, rotating, and expanding one. The inner portion of the nebula gives a continuous spectrum, very similar to that of a G type star, and is found to rotate, the speed being faster as we approach the edge. In other words, the inner portion rotates as a solid body. This motion of the inner portion is consistent with that of the outer portion, for material thrown off from the inner portion from two opposite parts of its surface would, under the attraction of gravity, form two spiral arms such as are found in this type of nebulae.

### *Globular Nebulae*

The globular nebulae form the other great non-galactic class. They are about as bright as the spiral nebulae, give a star-like spectrum, and, in general, are moving away from us at enormous velocities which may range from three hundred to eighteen hundred kilometers per second. In appearance they exhibit no spiral effect, the luminosity being continuous, brighter near the centre and gradually diminishing toward the edges. Their shapes range from spherical to that of a thin lens, being quite sharp at the edge, there being a continuous sequence from one extreme to the other. The distances of these nebulae have been determined to be from 3,000 to 30,000 light-years, so that in general they are about 100 light-years across. This means that they are of about the size of a globular star cluster and are much smaller than the Milky Way. Consequently the theory that they are "Island Universes" becomes untenable. Spectroscopic observations show that the central part of these nebulae rotate like a wheel but that, in the case of thin lens-shaped nebulae the velocity diminishes again toward the edge. This leads us to believe that the outer edge of these nebulae is composed of a thin sheet of matter thrown off by the central portion.

### *Nature of the Globular Nebula*

We must now determine the nature of these enormous bodies, whose total brightness is thousands of times that of the sun and

which rotate, giving off substance. Investigation has shown that a mass of rotating, incompressible liquid cannot become lens shaped, but that a mass of rotating gas becomes more and more flattened until the equator becomes almost a sharp edge, and that finally a thin sheet of material will be thrown off in the plane of the equator. In the globular nebulae we seem to have every stage of this process. If there were an even attraction all round the nebula the above would be the case, but the gravity effect of a star would produce tidal effects. Now at the points of high tide the gravity of the nebula would be lessened so that matter would come off most readily at two opposite points. As a result we would have a globular centre with two curved arms, exactly such a thing as a spiral nebula. This enables us to connect the two classes and gives us a continuous evolution from the spherical globular nebula to the extreme spiral nebula. Moreover, these long arms thrown off from the globular nebula will, being unstable bodies, break up into lumps in a manner similar to that in which a small jet of water breaks up into drops. Since this uneven distribution of matter is found in the arms of spiral nebulae the connection between the two types is still further shown.

### *Motion in a Spiral Nebula*

If we study closely the spiral nebulae we find that the arms always make the same angle with radii drawn from the centre, the forces being such that points on the spiral will always be on a similar spiral. Now the motions are not absolutely along the arms of the spiral but are such that the arms tend to curl up. This is not accounted for by gravitation and consequently there must be some other force, at present unknown, acting. However, if gravitation plays an important part, as it seems to, we can say that the mass of the nebulae must be millions of times that of the sun.

The non-galactic nebulae give the same type of spectrum as the stars, but cannot be separated into stars, even under the highest magnification. Thus we imagine them to be gigantic masses of luminous gas shining by their own light.

### *The Nebula about Nova Persei*

One other nebula, that surrounding Nova Persei, must be mentioned. This nebula moves extremely rapidly, the rate of

motion being certainly not less than 100,000 miles per second. In other words, the speed is comparable to that of light. The suggestion in this case is that there is cloud nebulosity surrounding the star, and that, as it blazed up and then faded out, a great hollow shell of light was given off, which, passing outward, illuminated the dark clouds as it came to them. This means that we actually see light passing outward through a stationary mass of reflecting clouds—a dark nebula.

## IX. Cosmogony

There remains to be discussed the subject of cosmogony, or the process by which the present state of things has been brought about. It is assuredly not for the scientist to say how matter first came to exist in space, but, having the matter already existing, it is his business to explain what has happened to it since.

### *Dark Nebula the Earliest State of Matter*

The present theory is that the dark nebula is the earliest state of matter. This is in turbid motion and composed of larger and smaller particles, the speed being probably too great for gravitation to act. Consequently the dark nebula itself will always remain the same.

However, due to the motion, bodies of matter will escape from the edges, and in these gravity will act, causing them to contract. As they contract, the particles, due to their motion, will collide, and consequently will be broken into smaller pieces and in course of time all particles will be broken into molecules, *i.e.*, the substance will become gaseous. As this contracts it will become hotter and will become visible as a red giant star. As it slowly and steadily continues to contract it will reach its maximum type, depending on its mass. If its mass is large it will become an O type star while if its mass is small it will become a star of type B. Then as it still contracts it will become cool and end by being a red dwarf and finally become too cool to emit light.

Moreover, if the mass of gas happens to be in rotation it will break up into two stars and form a close double. In the case of doubles having very eccentric orbits the theory is not so satisfactory, only fairly so.

Further, if the mass of gas is extremely large a nebula of the non-galactic type will be formed, while nebulae of the galactic type are merely dark nebulae shining under the influence of a neighbouring star.

Thus our theory of the development of the sidereal universe is fairly good.

### *Angular Momentum in Solar System*

In the solar system 98 per cent. of the angular momentum is in the planets and only two per cent. in the sun. Consequently we cannot account for the solar system by the rotation of a gaseous mass throwing off an unstable ring of matter, for in this case 98 per cent. of the angular momentum would not be possessed by the ring. Consequently we must find some other way by which this angular momentum was produced. This is done very well by the Planetesmal Theory.

### *The Planetesmal Theory*

According to this theory the sun was rotating slowly, and happened to come within the gravitational influence of a swiftly moving star. This attraction caused tides to form on the sides of the sun toward and opposite the star. This means that the sun's attraction on the matter forming the tidal bulge was diminished and, therefore, the equilibrium between gas pressure and gravitational attraction being destroyed, a huge eruption of material from each side of the sun took place. Then, as the star moved on, the ejected material formed two curved arms in the direction of the star's motion. After a short period, when the star had gone away, a quantity of the material in the arms fell back into the sun, but some remained going around the sun in the direction of the star's motion and in the same plane. This material was in the form of lumps of matter, but, in the course of time, the larger lumps picked up the smaller ones, having more free space and causing the orbits to become more circular. Calculation has shown that about four billion years were required to cause the orbits to become as circular as they now are. This figure agrees very well with that obtained by radio-active methods.

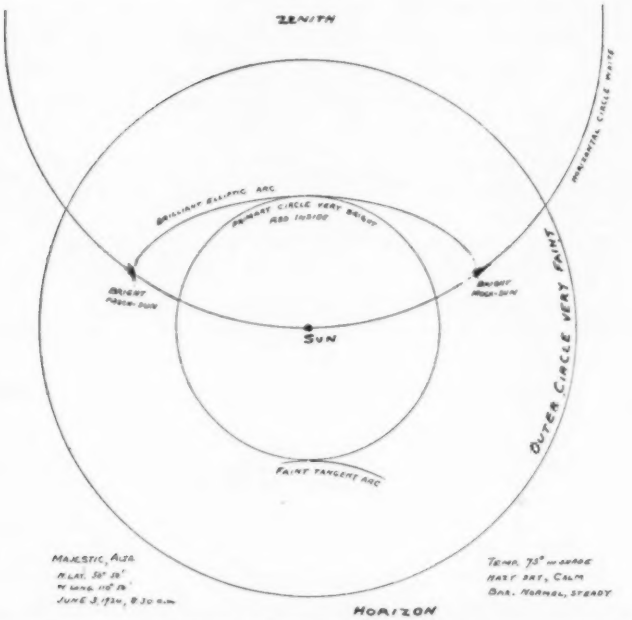
With the exception of the moon, the origin of the satellites can be explained on the same basis.

### *The Origin of the Moon*

To account for the moon, we must assume that the earth and moon were once a single mass moving around in five or six hours, and very flattened at the poles. Tides were then produced in the mass by the sun and these had the same period as the period of rotation. Since the two periods were the same, the tides increased in size until, finally, the pulsation was so great as to throw off the moon. After the resulting period of chaos, the system settled down, and tides were formed on the earth. These tides tend to slow down the earth's rotation and, consequently, energy must have been transferred to the moon, causing its orbit to increase in radius from 6,000 to 238,000 miles, as it is at present. As a matter of fact, the process is still going on, for, in 100 years, it takes one 1/1000th of a second longer for the earth to rotate, and, therefore, the moon is slowly increasing its distance.

### *Conclusion*

We have now shown how to sketch the evolution of the universe from its early stages to its present state, and how to account for the constitution of the solar system. Beyond this point the astronomer must turn over to the geologist and later to the biologist, in other words, the other students of that grand single order of nature, this noblest object of man's natural investigation, which is one of the best reasons for believing that there exists a Power behind it.




A Solar Halo Seen at Majestic, Alberta, by B. S. Wimbush

## A FINE SOLAR HALO IN ALBERTA

Mr. B. S. Wimbush describes the halo illustrated in the accompanying drawing as follows:—Enclosed is a brief account of an interesting and, for the time of the year, unusual phenomenon, which I have drawn to the best of my ability. It is the first ellipse that I have ever observed and it *is* an ellipse—not two circles at all —and the sun-dog is on the ellipse. It is hard to draw it as an ellipse, but there was no mistake about it. The mock-sun to the north of the sun was brighter than the other. The ellipse was connected with the primary circle as the red colour was joined to it. The horizontal circle was quite separate, being at a different place to the other circles. The tangent to the primary at the bottom is also an unusual thing. The upper part of the primary circle and the ellipse was as bright as the ordinary sun-dog. The high temperature was also unusual.

# AGINCOURT AND MEANOOK MAGNETIC RESULTS, 1922-1923

By W. E. W. Jackson

IN the accompanying tables there is given a summary of the results obtained at Agincourt and Meanook magnetic observatories during the years 1922 and 1923.

The values of Declination ($D$), Horizontal Force ($H$), and Vertical Force ($Z$), for Agincourt and of Declination for Meanook are obtained from mean hourly readings of the photographic records, based on absolute observations made each week for $D$ and $H$ and twice each week for the Inclination ($I$) by means of which the Vertical Force base is determined.

The mean values of $I$ for Agincourt are obtained from the means of $H$ and $Z$. The means of $H$ and of $I$ for Meanook are from absolute observations made twice each month for $H$ and each week for $I$, and are uncorrected for diurnal variations, but are taken alternately in morning and afternoon. The Meanook $Z$ is deduced from the mean $H$ and mean $I$. All observations are reduced to International Magnetic Standard.

Meteorological Office,
Toronto.

RESULTS OF MAGNETIC OBSERVATIONS AT AGINCOURT FOR 1922. LAT. 43° 47′ N.; LONG. 79° 16′ W.

Agincourt Declination West

| Month 1922 | Mean of Month | Maximum | Date of Max. | Minimum | Date of Min. | Month Range | Mean Daily Range: From 24-hour readings | Mean Daily Range: From Means of extremes |
|---|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | | ° ′ | | ° ′ | ′ | ′ |
| January | 6 53.4 | 7 24.2 | 25 | 6 32.7 | 6 | 0 51.5 | 5.5 | 17.3 |
| February | 6 54.6 | 7 26.9 | 16 | 6 29.5 | 14 | 0 57.4 | 6.6 | 19.0 |
| March | 6 55.0 | 7 22.2 | 13 | 6 26.9 | 1 | 0 55.3 | 9.3 | 21.2 |
| April | 6 55.2 | 7 23.3 | 27 | 6 10.2 | 21 | 1 13.1 | 10.9 | 26.4 |
| May | 6 55.6 | 7 42.4 | 7 | 6 30.8 | 7 | 1 11.6 | 11.8 | 20.8 |
| June | 6 55.6 | 7 19.8 | 5 | 6 28.1 | 16 | 0 51.7 | 11.6 | 21.2 |
| July | 6 56.1 | 7 17.8 | 29 | 6 17.9 | 28 | 0 59.9 | 12.2 | 21.7 |
| August | 6 56.7 | 7 23.2 | 12 | 6 25.5 | 12 | 0 57.7 | 12.5 | 23.4 |
| September | 6 57.2 | 7 26.7 | 14 | 6 27.7 | 14 | 0 59.0 | 9.8 | 22.6 |
| October | 6 58.1 | 7 25.8 | 5 | 6 19.1 | 30 | 1 06.7 | 6.7 | 20.1 |
| November | 6 58.2 | 7 15.4 | 29 | 6 22.1 | 27 | 0 53.3 | 6.4 | 14.6 |
| December | 6 58.5 | 7 11.0 | 2 | 6 42.0 | 14 | 0 29.0 | 4.9 | 10.0 |

Agincourt Horizontal Force

| Month 1922 | Mean of Month | Maximum | Date of Max. | Minimum | Date of Min. | Month Range | Mean Daily Range: From 24-hour readings | Mean Daily Range: From means of extremes |
|---|---|---|---|---|---|---|---|---|
| | γ | γ | | γ | | γ | γ | γ |
| January | 15821 | 15868 | 24 | 15718 | 25 | 150 | 21.6 | 54.4 |
| February | 15817 | 15903 | 7 | 15642 | 15 | 261 | 20.9 | 62.0 |
| March | 15810 | 15913 | 10 | 15444 | 14 | 469 | 30.2 | 92.6 |
| April | 15816 | 16002 | 21 | 15487 | 22 | 515 | 38.1 | 92.3 |
| May | 15816 | 15963 | 9 | 15657 | 7 | 306 | 31.0 | 84.6 |
| June | 15820 | 15902 | 28 | 15700 | 5 | 202 | 37.7 | 77.2 |
| July | 15813 | 15970 | 27 | 15710 | 29 | 260 | 31.5 | 85.5 |
| August | 15806 | 15875 | 11 | 15717 | 11 | 158 | 35.7 | 75.9 |
| September | 15798 | 15973 | 14 | 15592 | 14 | 381 | 31.2 | 79.9 |
| October | 15794 | 15874 | 30 | 15603 | 5 | 271 | 22.4 | 65.2 |
| November | 15800 | 15835 | 9 | 15705 | 3 | 130 | 16.8 | 47.2 |
| December | 15801 | 15843 | 26 | 15744 | 26 | 99 | 10.1 | 35.5 |

Agincourt Vertical Force

| Month 1922 | Mean of Month | Maximum | Date of Max. | Minimum | Date of Min. | Month Range | Mean Daily Range: From 24-hour readings | Mean Daily Range: From means of extremes |
|---|---|---|---|---|---|---|---|---|
| | γ | γ | | γ | | γ | γ | γ |
| January | 58017 | 58090 | 24 | 57905 | 25 | 185 | 8.8 | 27.6 |
| February | 58000 | 58020 | 9 | 57860 | 16 | 160 | 11.2 | 29.4 |
| March | 58000 | 58047 | 14 | 57775 | 14 | 272 | 24.4 | 50.7 |
| April | 57990 | 58146 | 21 | 57724 | 22 | 422 | 31.3 | 67.9 |
| May | 57972 | 58133 | 7 | 57830 | 7 | 303 | 20.3 | 54.6 |
| June | 57966 | 58031 | 30 | 57871 | 5 | 160 | 19.3 | 45.8 |
| July | 57953 | 58054 | 28 | 57804 | 29 | 250 | 23.5 | 51.6 |
| August | 57932 | 57972 | 9 | 57840 | 20 | 132 | 20.7 | 48.5 |
| September | 57932 | 58154 | 14 | 57713 | 14 | 441 | 31.2 | 59.1 |
| October | 57927 | 58084 | 30 | 57822 | 5 | 262 | 16.5 | 43.9 |
| November | 57929 | 57954 | 27 | 57887 | 2 | 67 | 4.5 | 14.7 |
| December | 57916 | 57940 | 5 | 57877 | 26 | 63 | 3.6 | 8.0 |

RESULTS OF MAGNETIC OBSERVATIONS AT MEANOOK FOR 1922.
LAT. 54° 37′ N.; LONG. 113° 20′ W.

Meanook Declination East

| Month 1922 | Mean of Month | Maximum | Date of Max. | Minimum | Date of Min. | Month Range | Mean Daily Range: From 24-hour readings | Mean Daily Range: From means of extremes |
|---|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | | ° ′ | | ° ′ | ′ | ′ |
| January | 27 31.6 | 28 45.7 | 24 | 26 19.2 | 24 | 2 26.5 | 5.3 | 31.1 |
| February | 32.2 | 30 18.4 | 16 | 26 19.2 | 14 | 3 59.2 | 7.1 | 49.8 |
| March | 30.0 | 29 27.0 | 14 | 25 27.9 | 14 | 3 59.1 | 10.4 | 50.5 |
| April | 27.4 | 28 20.2 | 24 | 25 26.6 | 21 | 2 53.6 | 11.7 | 50.8 |
| May | 25.9 | 28 23.8 | 10 | 26 48.6 | 10 | 1 35.2 | 13.9 | 33.4 |
| June | 28.1 | 28 36.7 | 30 | 26 28.3 | 5 | 2 08.4 | 14.8 | 33.4 |
| July | 28.3 | 28 42.4 | 27 | 26 28.9 | 27 | 2 13.5 | 13.9 | 37.7 |
| August | 28.9 | 29 33.7 | 11 | 26 36.3 | 21 | 2 57.4 | 14.8 | 44.9 |
| September | 29.1 | 30 05.4 | 14 | 26 06.0 | 14 | 3 59.4 | 15.4 | 50.2 |
| October | 28.2 | 30 05.3 | 5 | 26 08.4 | 5 | 3 56.9 | 9.4 | 42.3 |
| November | 26.9 | 28 06.5 | 29 | 26 58.9 | 29 | 1 07.6 | 5.3 | 19.8 |
| December | 25.5 | 28 03.5 | 26 | 26 55.7 | 10 | 1 07.8 | 4.2 | 18.9 |

MEAN MONTHLY VALUES OF *I* AT AGINCOURT AND MEANOOK AND OF *H* AND *Z* AT MEANOOK FOR 1922

| Month 1922 | Ag. *I.* | Me. *I.* | Me. *H.* | Me. *Z.* |
|---|---|---|---|---|
| | ° ′ | ° ′ | γ | γ |
| January | 74 44.8 | 77 53.6 | 12908 | 60176 |
| February | 44.8 | 53.1 | 12920 | 60189 |
| March | 45.1 | 53.7 | 12890 | 60101 |
| April | 44.7 | 54.0 | 12910 | 60220 |
| May | 44.4 | 53.8 | 12897 | 60142 |
| June | 44.1 | 53.6 | 12905 | 60162 |
| July | 44.3 | 52.7 | 12921 | 60160 |
| August | 44.3 | 52.6 | 12909 | 60096 |
| September | 44.8 | 53.4 | 12896 | 60103 |
| October | 44.9 | 53.4 | 12862 | 59945 |
| November | 44.6 | 53.3 | 12907 | 60146 |
| December | 44.4 | 52.9 | 12899 | 60075 |

RESULTS OF MAGNETIC OBSERVATIONS AT AGINCOURT FOR 1923.
LAT. 43° 47′ N.; LONG. 79° 16′ W.

Agincourt Declination West

| Month 1923 | Mean of Month | Maximum | Date of Max. | Minimum | Date of Min. | Month Range | Mean Daily Range: From 24-hour readings | Mean Daily Range: From means of extremes |
|---|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | | ° ′ | | ° ′ | ′ | ′ |
| January | 6 58.6 | 7 13.9 | 22 | 6 39.4 | 13 | 0 34.5 | 7.4 | 12.2 |
| February | 6 59.3 | 7 18.9 | 26 | 6 10.8 | 25 | 1 08.1 | 6.8 | 14.7 |
| March | 7 00.0 | 8 07.4 | 24 | 6 18.6 | 24 | 1 48.8 | 8.9 | 16.5 |
| April | 7 00.3 | 7 20.9 | 20 | 6 41.7 | 13 | 0 39.2 | 11.7 | 15.8 |
| May | 7 00.4 | 7 20.0 | 17 | 6 38.5 | 17 | 0 41.5 | 10.7 | 14.8 |
| June | 7 00.2 | 7 25.1 | 30 | 6 10.1 | 12 | 1 15.1 | 11.9 | 18.6 |
| July | 7 00.0 | 7 15.4 | 6 | 6 41.4 | 9 | 0 34.0 | 9.8 | 13.9 |
| August | 7 01.9 | 7 15.2 | 3 | 6 49.2 | 13 | 0 26.0 | 10.6 | 13.0 |
| September | 7 01.7 | 7 59.9 | 26 | 5 41.4 | 26 | 2 18.5 | 10.3 | 18.6 |
| October | 7 02.2 | 7 38.9 | 16 | 5 57.5 | 16 | 1 41.4 | 6.2 | 17.0 |
| November | 7 02.7 | 7 16.1 | 3 | 6 43.2 | 2 | 0 32.9 | 6.8 | 10.8 |
| December | 7 03.4 | 7 18.3 | 26 | 6 52.4 | 10 | 0 25.9 | 4.4 | 9.1 |

Agincourt Horizontal Force

| Month 1923 | Mean of Month | Maximum | Date of Max. | Minimum | Date of Min. | Month Range | Mean Daily Range | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | From 24-hour readings | From means of extremes |
| | γ | γ | | γ | | γ | γ | γ |
| January | 15799 | 15828 | 20 | 15753 | 23 | 75 | 26.7 | 42.9 |
| February | 15794 | 15853 | 25 | 15695 | 25 | 158 | 20.9 | 47.2 |
| March | 15790 | 16048 | 24 | 15473 | 24 | 575 | 30.2 | 67.7 |
| April | 15790 | 15836 | 20 | 15735 | 23 | 101 | 38.1 | 57.4 |
| May | 15791 | 15844 | 29 | 15710 | 17 | 134 | 31.0 | 51.6 |
| June | 15790 | 15897 | 12 | 15709 | 13 | 188 | 37.7 | 64.0 |
| July | 15788 | 15841 | 6 | 15708 | 6 | 133 | 31.5 | 54.9 |
| August | 15782 | 15857 | 13 | 15732 | 4 | 125 | 35.7 | 53.2 |
| September | 15777 | 15845 | 27 | 15560 | 27 | 285 | 31.2 | 65.4 |
| October | 15767 | 15805 | 15 | 15606 | 17 | 199 | 22.4 | 42.4 |
| November | 15768 | 15789 | 2 | 15735 | 2 | 54 | 16.7 | 24.1 |
| December | 15768 | 15784 | 4 | 15734 | 25 | 50 | 10.1 | 17.6 |

Agincourt Vertical Force

| Month 1923 | Mean of Month | Maximum | Date of Max. | Minimum | Date of Min. | Month Range | Mean Daily Range | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | From 24-hour readings | From means of extremes |
| | γ | γ | | γ | | γ | γ | γ |
| January | 57899 | 57915 | 4 | 57876 | 21 | 39 | 3.5 | 8.9 |
| February | 57895 | 57991 | 25 | 57836 | 25 | 155 | 7.2 | 17.8 |
| March | 57889 | 58061 | 24 | 57686 | 24 | 375 | 7.4 | 25.3 |
| April | 57870 | 57887 | 22 | 57801 | 20 | 86 | 6.5 | 14.6 |
| May | 57851 | 57880 | 17 | 57775 | 17 | 105 | 8.1 | 18.8 |
| June | 57858 | 57929 | 12 | 57728 | 13 | 201 | 12.7 | 35.2 |
| July | 57849 | 57875 | 6 | 57794 | 6 | 81 | 5.8 | 18.5 |
| August | 57827 | 57852 | 3 | 57781 | 3 | 71 | 7.8 | 18.4 |
| September | 57817 | 58016 | 27 | 57626 | 27 | 390 | 13.0 | 40.0 |
| October | 57818 | 57914 | 16 | 57707 | 17 | 207 | 14.2 | 31.5 |
| November | 57812 | 57823 | 2 | 57743 | 2 | 80 | 4.7 | 10.7 |
| December | 57798 | 57812 | 9 | 57780 | 26 | 32 | 3.3 | 6.5 |

RESULTS OF MAGNETIC OBSERVATIONS AT MEANOOK FOR 1923.
LAT. 54° 37′ N.; LONG. 113° 20′ W.

Meanook Declination East

| Month 1923 | Mean of Month | Maximum | Date of Max. | Minimum | Date of Min. | Month Range | Mean Daily Range | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | From 24-hour readings | From means of extremes |
| | ° ′ | ° ′ | | ° ′ | | ° ′ | ′ | ′ |
| January | 27 26.3 | 28 04.5 | 20 | 26 48.6 | 22 | 1 15.9 | 6.3 | 19.2 |
| February | 25.7 | 27 57.9 | 7 | 25 45.5 | 25 | 2 12.4 | 5.8 | 24.9 |
| March | 24.2 | 29 20.6 | 24 | 26 03.7 | 24 | 3 16.9 | 7.6 | 25.0 |
| April | 21.9 | 28 02.6 | 20 | 26 56.6 | 11 | 1 06.0 | 10.8 | 20.7 |
| May | 20.6 | 27 57.6 | 17 | 26 54.2 | 18 | 1 03.4 | 11.8 | 19.5 |
| June | 22.4 | 28 14.7 | 30 | 26 24.5 | 13 | 1 50.2 | 13.2 | 25.8 |
| July | 23.3 | 27 57.0 | 10 | 26 55.3 | 6 | 1 01.7 | 12.2 | 19.6 |
| August | 23.5 | 27 53.9 | 3 | 26 52.0 | 3 | 1 01.9 | 12.8 | 19.2 |
| September | 23.1 | 28 23.8 | 28 | 26 23.1 | 28 | 2 00.7 | 9.7 | 23.8 |
| October | 23.1 | 29 03.3 | 15 | 26 27.9 | 16 | 2 35.4 | 5.9 | 28.1 |
| November | 23.2 | 28 14.1 | 1 | 27 3.3 | 2 | 1 10.8 | 6.0 | 15.8 |
| December | 21.9 | 27 52.4 | 26 | 26 56.0 | 26 | 0 56.4 | 5.1 | 16.1 |

MEAN MONTHLY VALUES OF *I* AT AGINCOURT AND MEANOOK AND OF *H* AND *Z* AT MEANOOK FOR 1923

| Month 1923 | Ag. *I.* | Me. *I.* | Me. *H.* | Me. *Z.* |
|---|---|---|---|---|
| | ° ′ | ° ′ | γ | γ |
| January | 74 44.2 | 77 53.1 | 12896 | 60078 |
| February | 44.4 | 52.8 | ..... | ..... |
| March | 44.6 | 53.5 | 12886 | 60065 |
| April | 44.3 | 53.5 | 12881 | 60042 |
| May | 44.0 | 53.6 | 12888 | 60083 |
| June | 44.1 | 52.3 | 12891 | 59986 |
| July | 44.1 | 52.7 | ..... | ..... |
| August | 44.0 | 52.4 | 12871 | 59902 |
| September | 44.2 | 53.6 | 12866 | 59980 |
| October | 44.8 | 53.9 | 12869 | 60020 |
| November | 44.6 | 53.9 | 12891 | 60123 |
| December | 44.4 | 53.1 | 12873 | 59971 |

# WIRELESS TIME SIGNALS OBSERVED AT OTTAWA

By R. Meldrum Stewart

*Bulletin No. 6*

FOR the Annapolis and Lafayette signals the quantities given and their arrangement are the same as in previous bulletins.

From about the beginning of December Honolulu (NPM) sent twice daily, shortly after 0h and 12h G.M.T. (7 a.m. and 7 p.m. E.S.T.), a series of scientific signals for use in determining Australian longitudes. It was intended that each series should consist of 300 beats, of which the 60th, 120th...300th were omitted for the purpose of reference, the interval between consecutive beats being .98 sec. (mean time). Up to December 17 or 18, however, this interval was .9980 sec.; from that time to the end of the month it was .9799 sec. On many occasions also the series did not cover exactly 300 beats, and did not begin with the beat immediately following an omitted one. The times given are those corresponding to the 150th beat of a theoretically complete series; that is, they correspond in every case to the beat midway between two consecutive omissions, irrespective of whether the series was complete or not. For comparison with other observations these results may be reduced to refer to any other chosen beat by the use of the sidereal intervals given in the last column, which may be taken as exact in all cases. They have been deduced from the intervals between consecutive series of signals; the greatest variation found either from 12h or 24h intervals was about one unit in the fifth place, showing that the variations in the rate of the sending chronometer, either diurnal or otherwise, were probably negligible.

For reference there are also given the observed errors of the ordinary signals immediately preceding, which however are quite erratic. The alternate intervals of these ordinary signals were quite unequal; that is, the transmitting clock was decidedly out of beat; the figures given refer to the means of alternate beats.

The signals were frequently weak, and receiving conditions adverse; occasionally, perhaps even frequently, the errors of reception may have amounted to as much as .05 sec. Further results will appear in later bulletins.

The adopted longitude of Ottawa is 5h 2m 51.940s.

Dominion Observatory, Ottawa, May, 1924.

WIRELESS TIME SIGNALS OBSERVED AT OTTAWA

| 1923 | Ottawa—Washington | | | | Lafayette (G. Sid. T.) | | ΔT at 10 p.m. | |
|---|---|---|---|---|---|---|---|---|
| Date | Observed | | Corrected | | 1st Beat | 300th Beat | Observed | Adopted |
| | Noon | 10 p.m. | Noon | 10 p.m. | | | | |
| | s | s | s | s | h m s | h m s | s | s |
| Sept. 1 | +.03 | +.03 | −.04 | −.04 | 18 48 0.56 | 18 52 53.77 | −17.274 | −17.276 |
| 2 | +.01 | +.03 | −.04 | −.01 | 50 34.47 | 55 27.68 | ..... | −17.498 |
| 3 | +.04 | +.07 | +.01 | +.01 | 53 43.34 | 58 36.57 | ..... | −17.709 |
| 4 | +.06 | +.03 | +.01 | −.03 | 55 24.00 | 19 0 17.21 | ..... | −17.944 |
| 5 | +.08 | +.05 | +.02 | +.01 | ..... | ..... | −18.174 | −18.183 |
| 6 | .... | +.05 | .... | .00 | 19 4 19.09 | 9 12.30 | −18.431 | −18.413 |
| 7 | +.03 | +.02 | −.01 | −.02 | 9 55.47 | 14 48.70 | −18.637 | −18.637 |
| 8 | +.03 | +.03 | −.03 | −.02 | 15 52.34 | 20 45.57 | ..... | −18.844 |
| 9 | +.06 | +.07 | −.02 | +.01 | 13 28.04 | 18 21.27 | ..... | −19.032 |
| 10 | +.07 | +.09 | −.01 | .00 | 18 2.04 | 22 55.26 | −19.239 | −19.238 |
| 11 | +.05 | +.04 | .00 | −.01 | 25 10.27 | 30 3.49 | ..... | −19.448 |
| 12 | +.04 | +.01 | −.05 | −.05 | 28 4.59 | 32 57.82 | −19.586 | −19.607 |
| 13 | +.05 | +.07 | −.03 | −.02 | 33 17.17 | 38 10.38 | −19.866 | −19.851 |
| 14 | +.03 | +.05 | −.05 | −.03 | 38 22.95 | 43 16.20 | −20.114 | −20.105 |
| 15 | ..... | +.12 | ..... | +.02 | ..... | ..... | −20.324 | −20.331 |
| 16 | +.09 | +.12 | −.01 | .00 | ..... | ..... | ..... | −20.555 |
| 17 | +.10 | +.13 | .00 | +.03 | 49 11.57 | 54 4.80 | −20.794 | −20.769 |
| 18 | +.11 | +.12 | +.02 | +.02 | 20 4 23.03 | 20 9 16.24 | ..... | −20.991 |
| 19 | +.10 | +.10 | +.01 | .00 | 19 58 26.81 | 3 20.04 | −21.169 | −21.219 |
| 20 | +.02 | +.07 | −.01 | +.02 | 59 24.36 | 4 17.59 | ..... | −21.446 |
| 21 | +.07 | +.09 | +.02 | +.04 | 20 4 17.36 | 9 10.58 | −21.747 | −21.705 |
| 22 | +.02 | +.04 | .00 | +.01 | 8 46.05 | 13 39.27 | −21.900 | −21.935 |
| 23 | +.01 | +.03 | .00 | +.01 | 18 26.51 | 23 19.73 | −22.197 | −22.185 |
| 24 | +.12 | +.11 | +.02 | +.01 | 15 39.81 | 20 33.04 | −22.436 | −22.428 |
| 25 | +.10 | +.08 | .00 | −.04 | ..... | ..... | −22.644 | −22.630 |
| 26 | +.06 | +.06 | −.03 | −.02 | 24 26.36 | 29 19.60 | ..... | −22.824 |
| 27 | +.03 | +.07 | −.04 | −.03 | 30 11.59 | 35 4.82 | ..... | −23.006 |
| 28 | +.04 | +.05 | −.04 | −.04 | 38 46.41 | 43 39.63 | ..... | −23.195 |
| 29 | +.05 | +.07 | −.03 | −.01 | 57 17.49 | 21 2 10.71 | −23.384 | −23.384 |
| 30 | +.03 | +.06 | −.06 | −.05 | 21 1 58.77 | 6 52.00 | ..... | −23.575 |

## WIRELESS TIME SIGNALS OBSERVED AT OTTAWA

| 1923 Date | Ottawa—Washington Observed | | Ottawa—Washington Corrected | | Lafayette (G. Sid. T.) | | ΔT at 10 p.m. | |
|---|---|---|---|---|---|---|---|---|
| | Noon | 10 p.m. | Noon | 10 p.m. | 1st Beat | 300th Beat | Observed | Adopted |
| | s | s | s | s | h m s | h m s | s | s |
| Oct. 1 | +.04 | +.05 | −.06 | −.06 | 20 56 46.71 | 21 1 39.93 | −23.773 | −23.769 |
| 2 | +.02 | +.05 | −.04 | −.02 | 44 37.85 | 20 49 31.04 | −23.954 | −23.957 |
| 3 | +.06 | +.07 | −.01 | −.01 | 56 44.17 | 21 1 37.38 | ..... | − 0.409 |
| 4 | +.13 | +.12 | −.02 | −.02 | 21 5 20.60 | 10 13.82 | ..... | − 0.252 |
| 5 | +.10 | +.13 | −.02 | −.01 | 20 58 11.90 | 3 5.12 | − 0.097 | − 0.095 |
| 6 | −.05 | +.04 | −.03 | −.03 | 21 0 42.82 | 5 36.07 | ..... | + 0.061 |
| 7 | +.05 | +.09 | −.02 | .00 | 20 26.58 | 25 19.80 | + 0.222 | + 0.218 |
| 8 | +.03 | +.06 | −.02 | −.01 | 29 43.62 | 34 36.84 | + 0.368 | + 0.377 |
| 9 | +.04 | +.05 | −.03 | −.02 | 15 10.90 | 20 4.12 | + 0.533 | + 0.545 |
| 10 | +.08 | +.07 | +.02 | +.01 | ..... | ..... | ..... | + 0.718 |
| 11 | +.06 | +.09 | .00 | +.02 | 24 29.05 | 29 22.28 | + 0.906 | + 0.891 |
| 12 | +.11 | +.13 | −.01 | .00 | 31 26.75 | 36 19.96 | + 1.059 | + 1.055 |
| 13 | +.13 | +.11 | −.01 | −.01 | 36 1.25 | 40 54.48 | ..... | + 1.212 |
| 14 | +.05 | +.07 | −.02 | −.01 | 38 41.04 | 43 34.26 | + 1.364 | + 1.374 |
| 15 | +.05 | +.07 | −.02 | −.01 | 41 36.76 | 46 29.99 | + 1.520 | + 1.548 |
| 16 | +.05 | +.09 | −.01 | +.03 | 44 11.96 | 49 5.17 | + 1.750 | + 1.736 |
| 17 | +.05 | +.09 | .00 | +.03 | 48 45.01 | 53 38.23 | + 1.931 | + 1.922 |
| 18 | +.13 | +.14 | +.04 | +.05 | 22 4 5.47 | 22 8 58.70 | ..... | + 2.117 |
| 19 | +.22 | +.14 | +.15 | +.08 | 21 57 50.39 | 2 43.61 | ..... | + 2.280 |
| 20 | +.10 | +.15 | +.04 | +.09 | 22 1 24.72 | 6 17.94 | + 2.470 | + 2.446 |
| 21 | +.16 | +.09 | +.08 | +.04 | 3 1.13 | 7 54.35 | + 2.573 | + 2.602 |
| 22 | +.18 | +.17 | +.06 | +.06 | 6 35.18 | 11 28.39 | + 2.774 | + 2.768 |
| 23 | +.17 | +.11 | +.04 | .00 | 12 6.75 | 16 59.96 | ..... | + 2.940 |
| 24 | +.18 | +.14 | +.04 | .00 | 16 39.54 | 21 32.76 | ..... | + 3.108 |
| 25 | +.10 | +.06 | +.02 | −.02 | 20 13.69 | 25 6.93 | ..... | + 3.275 |
| 26 | +.08 | +.10 | +.02 | +.02 | 22 48.96 | 27 42.18 | + 3.439 | + 3.442 |
| 27 | +.15 | +.17 | +.04 | +.05 | 28 20.57 | 33 13.80 | + 3.620 | + 3.620 |
| 28 | +.15 | +.15 | +.03 | +.04 | 30 55.63 | 35 48.84 | ..... | + 3.796 |
| 29 | +.12 | +.15 | +.02 | +.02 | 34 29.65 | 39 22.87 | + 3.976 | + 3.980 |
| 30 | +.15 | +.17 | +.02 | +.03 | 47 52.07 | 52 45.31 | ..... | + 4.162 |
| 31 | +.19 | +.17 | +.02 | .00 | 44 42.88 | 49 36.11 | ..... | + 4.351 |

## WIRELESS TIME SIGNALS OBSERVED AT OTTAWA

| 1923 | Ottawa—Washington | | | | Lafayette (G. Sid. T.) | | ΔT at 10 p.m. | |
|---|---|---|---|---|---|---|---|---|
| Date | Observed | | Corrected | | 1st Beat | 300th Beat | Observed | Adopted |
| | Noon | 10 p.m. | Noon | 10 p.m. | | | | |
| | s | s | s | s | h m s | h m s | s | s |
| Nov. 1 | +.16 | +.19 | .00 | +.02 | 22 45 20.82 | 22 50 14.05 | +4.549 | + 4.543 |
| 2 | +.14 | +.11 | ..... | +.04 | 50 52.49 | 55 45.72 | +4.732 | + 4.730 |
| 3 | +.14 | +.08 | ..... | ..... | 56 24.85 | 23 1 18.06 | +4.914 | + 4.911 |
| 4 | +.08 | +.10 | .00 | +.03 | 23 1 56.04 | 6 49.26 | ..... | + 5.082 |
| 5 | +.08 | +.09 | .00 | +.01 | 6 27.79 | 11 21.01 | ..... | + 5.252 |
| 6 | +.07 | +.08 | .00 | .00 | 11 0.07 | 15 53.30 | ..... | + 5.431 |
| 7 | +.09 | +.04 | +.01 | −.05 | 24 22.00 | 29 15.23 | ..... | + 5.610 |
| 8 | +.09 | +.05 | .00 | −.04 | 37 51.13 | 42 44.35 | +5.806 | + 5.815 |
| 9 | +.10 | +.11 | −.01 | −.01 | 18 24.20 | 23 17.45 | ..... | + 6.032 |
| 10 | +.09 | +.13 | −.01 | +.02 | ..... | ..... | ..... | + 6.258 |
| 11 | +.13 | +.15 | .00 | .00 | 25 49.25 | 30 42.50 | ..... | + 6.487 |
| 12 | +.16 | +.15 | −.01 | −.02 | 31 29.25 | 36 22.50 | ..... | + 6.709 |
| 13 | +.13 | +.19 | −.04 | −.01 | 40 5.67 | 44 58.92 | +6.957 | + 6.937 |
| 14 | +.12 | +.09 | +.02 | −.01 | 47 42.79 | 52 36.04 | ..... | + 7.147 |
| 15 | +.05 | .00 | −.02 | −.04 | 41 36.12 | 46 29.37 | ..... | + 7.360 |
| 16 | −.01 | .00 | −.04 | −.04 | 51 10.98 | 56 4.23 | ..... | + 7.565 |
| 17 | −.04 | −.07 | −.05 | −.06 | 51 50.04 | 56 43.29 | ..... | + 7.769 |
| 18 | −.02 | +.02 | −.06 | −.04 | 57 40.76 | 0 2 34.00 | ..... | + 7.983 |
| 19 | +.01 | −.02 | −.04 | −.06 | 58 22.01 | 3 15.25 | ..... | + 8.210 |
| 20 | +.05 | +.01 | −.06 | −.05 | 0 2 59.19 | 7 52.43 | ..... | + 8.436 |
| 21 | +.04 | +.02 | −.03 | −.04 | 11 27.48 | 16 20.72 | ..... | + 8.660 |
| 22 | +.05 | +.02 | −.03 | −.05 | 14 50.99 | 19 44.21 | +8.894 | + 8.890 |
| 23 | +.08 | +.13 | −.02 | −.02 | 16 33.04 | 21 26.27 | ..... | + 9.123 |
| 24 | +.14 | +.14 | −.01 | ..... | 16 17.18 | 21 10.42 | ..... | + 9.358 |
| 25 | +.10 | +.13 | +.01 | +.02 | 25 55.01 | 30 48.24 | ..... | + 9.589 |
| 26 | +.11 | +.10 | .00 | .00 | 38 22.72 | 43 15.99 | ..... | + 9.800 |
| 27 | +.10 | +.12 | .00 | +.02 | 29 11.63 | 34 4.84 | ..... | +10.020 |
| 28 | +.12 | +.08 | .00 | −.02 | 36 32.42 | 41 25.67 | ..... | +10.224 |
| 29 | +.05 | +.08 | −.01 | .00 | 39 18.04 | 44 11.30 | ..... | +10.441 |
| 30 | +.06 | +.04 | .00 | .00 | 43 58.93 | 48 52.18 | ..... | +10.661 |

## WIRELESS TIME SIGNALS OBSERVED AT OTTAWA

| 1923 | Ottawa—Washington | | | | Lafayette (G. Sid. T.) | | ΔT at 10 p.m. | |
|---|---|---|---|---|---|---|---|---|
| Date | Observed | | Corrected | | 1st Beat | 300th Beat | Observed | Adopted |
| | Noon | 10 p.m. | Noon | 10 p.m. | | | | |
| | s | s | s | s | h m s | h m s | s | s |
| Dec. 1 | ..... | +.07 | ..... | +.01 | 0 47 23.73 | 0 52 16.97 | ..... | +10.879 |
| 2 | ..... | +.09 | ..... | +.03 | 1 0 55.32 | 1 5 48.56 | ..... | +11.106 |
| 3 | ..... | +.07 | ..... | +.02 | 17 21.44 | 22 14.69 | +11.333 | +11.333 |
| 4 | ..... | +.12 | ..... | +.04 | 0 57 30.11 | 2 23.33 | ..... | +11.565 |
| 5 | +.14 | +.09 | +.05 | +.05 | 1 4 7.49 | 9 0.73 | ..... | +11.797 |
| 6 | +.11 | +.12 | +.03 | +.04 | 14 40.47 | 19 33.71 | ..... | +12.020 |
| 7 | ..... | +.10 | ..... | +.02 | 20 19.18 | 25 12.43 | ..... | +12.245 |
| 8 | ..... | +.08 | ..... | +.02 | 12 14.05 | 17 7.29 | ..... | +12.455 |
| 9 | +.14 | +.14 | +.01 | +.02 | 14 56.26 | 19 49.51 | +12.679 | +12.679 |
| 10 | ..... | +.14 | ..... | +.01 | 20 35.33 | 25 28.57 | ..... | +12.907 |
| 11 | +.17 | +.16 | +.01 | .00 | 27 13.05 | 32 6.29 | +13.124 | +13.144 |
| 12 | +.08 | +.12 | −.02 | .00 | 26 0.20 | 30 53.44 | ..... | +13.394 |
| 13 | +.09 | +.08 | .00 | −.01 | 36 33.39 | 41 26.63 | ..... | +13.636 |
| 14 | +.09 | +.07 | .00 | −.01 | 35 20.42 | 40 13.66 | +13.894 | +13.889 |
| 15 | +.09 | +.12 | −.01 | +.02 | 40 0.64 | 44 53.89 | ..... | +14.138 |
| 16 | +.12 | +.12 | .00 | .00 | 42 42.77 | 47 36.02 | ..... | +14.378 |
| 17 | +.06 | −.02 | .00 | −.01 | 2 23 40.48 | 2 28 33.73 | +14.618 | +14.617 |
| 18 | +.07 | +.05 | +.02 | −.01 | 1 54 59.70 | 1 59 52.93 | +14.841 | +14.863 |
| 19 | +.07 | +.08 | −.01 | −.01 | 55 44.16 | 2 0 37.41 | ..... | +15.114 |
| 20 | +.10 | +.12 | +.01 | +.03 | 2 2 22.68 | 7 15.92 | ..... | +15.365 |
| 21 | +.14 | +.13 | +.04 | +.04 | 3 7.20 | 8 0.45 | ..... | +15.626 |
| 22 | +.22 | +.14 | +.10 | +.05 | 5 49.28 | 10 42.52 | ..... | +15.890 |
| 23 | +.21 | +.19 | +.09 | +.09 | 10 30.65 | 15 23.90 | ..... | +16.151 |
| 24 | +.15 | +.18 | +.07 | +.05 | 14 11.95 | 19 5.19 | ..... | +16.404 |
| 25 | +.13 | +.13 | +.05 | +.05 | 18 53.15 | 23 46.39 | ..... | +16.654 |
| 26 | +.12 | +.14 | +.06 | +.08 | 22 33.79 | 27 27.03 | ..... | +16.897 |
| 27 | +.11 | +.15 | +.07 | +.09 | 26 15.13 | 31 8.37 | ..... | +17.137 |
| 28 | +.13 | +.13 | +.05 | +.05 | 29 56.41 | 34 49.66 | ..... | +17.373 |
| 29 | +.15 | +.15 | +.09 | +.09 | 39 30.44 | 44 23.69 | ..... | +17.608 |
| 30 | +.15 | +.14 | +.06 | +.06 | ..... | ..... | ..... | +17.842 |
| 31 | +.10 | +.10 | +.01 | +.01 | ..... | ..... | ..... | +18.073 |

HONOLULU TIME SIGNALS

| 1923 | Ordinary | | Scientific (G. Sid. T.) | | Sidereal |
|---|---|---|---|---|---|
| Date | 7 a.m. | 7 p.m. | 7 a.m. | 7 p.m. | Interval |
| | s | s | h m s | h m s | s |
| Dec. 11 | .00 | ..... | ..... | ..... | ..... |
| 12 | − .22 | ..... | 17 24 23.85 | ..... | 1.0007 |
| 13 | − .84 | ..... | 28 26.00 | ..... | " |
| 14 | − .68 | ..... | 32 28.19 | ..... | " |
| 15 | − .84 | −.99 | ..... | ..... | ..... |
| 16 | − .50 | +.34 | 41 5.71 | 5 41 36.72 | " |
| 17 | + .13 | ..... | 43 7.61 | ..... | " |
| 18 | ..... | ..... | ..... | ..... | ..... |
| 19 | + .92 | ..... | 51 52.42 | ..... | .9826 |
| 20 | + .32 | −.07 | 56 16.31 | ..... | " |
| 21 | − .02 | ..... | 59 41.59 | ..... | " |
| 22 | ..... | −.35 | ..... | ..... | ..... |
| 23 | − .96 | ..... | 18 7 32.17 | ..... | " |
| 24 | −1.06 | −.06 | 10 57.60 | ..... | " |
| 25 | + .16 | +.50 | 15 22.08 | 6 17 34.32 | " |
| 26 | +1.08 | ..... | 19 46.25 | ..... | " |
| 27 | − .01 | +.54 | 23 11.34 | 25 23.35 | " |
| 28 | + .14 | +.54 | 27 35.24 | 28 48.58 | " |
| 29 | .00 | −.01 | 31 0.43 | 33 12.42 | " |
| 30 | − .29 | −.44 | 35 24.36 | 36 37.50 | " |
| 31 | − .54 | ..... | ..... | ..... | ..... |

# THE DIURNAL INEQUALITY OF DECLINATION AT AKLAVIK, N.W.T.

By W. H. HERBERT

SINCE the inception in 1880 of the magnetic survey of the Topographical Survey of Canada nearly 20,000 accurate declination observations have been made at no cost, by using bearings of the land survey and observing with an accurate trough or telescopic compass attached to a high-class theodolite, when not engaged on other work; and these observations have been corrected for the daily march of the needle by applying the diurnal inequality correction for the time of observation.

Although this correction is accurately known at such observatories as Agincourt, Ont.; Meanook, Alta., and Sitka, Alaska, the small amount of miscellaneous data available for the northern districts at such places as Forts Rae, Reliance and Franklin, N.W.T., and Uglaamie, Alaska, does not afford a very reliable knowledge; more especially as in these districts the correction varies so rapidly with position, on account of nearness to the north magnetic pole in King William Island on the Arctic coast of Canada.

It is therefore necessary to measure this diurnal inequality correction at northern points in order that declination observations in those districts may be accurately corrected for the daily march of the needle.

During the winter of 1922-23 Mr. B. H. Segré, D.L.S., remained at Aklavik, N.W.T., about fifty miles below Fort McPherson in latitude 68° 13′ N. and longitude 134° 59′ W., and was therefore instructed to make hourly observations of this diurnal inequality during the winter when not engaged on survey work.

The instrument used was a high-class five-inch Cooke theodolite equipped with a telescopic compass standardized at the Agincourt Magnetic Observatory, both before and after use, and capable of observing declination with a probable error much less than one minute. It was mounted in a tent apart from any building or

other local disturbing influence and oriented on a distant permanent reference mark.

For the eight months October, 1922, to May, 1923, inclusive, hourly observations on ten days each month, spaced three days apart, were made from 7 a.m. to 5 p.m. Yukon standard time, which is practically the same as local mean time. The mean results of these observations follow and exhibit very clearly the considerable value of the diurnal inequality in this region.

DIURNAL INEQUALITY OF DECLINATION, AKLAVIK, N.W.T.
1922-1923

Longitude 134° 59′ W. Latitude 68° 13′ N.

| Yukon Std. Time | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May |
|---|---|---|---|---|---|---|---|---|
| | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| 7 a.m. | 21.8 E | 17.0 E | 11.9 E | 10.9 E | 12.4 E | 14.3 E | 18.2 E | 22.1 E |
| 8 " | 16.3 E | 12.3 E | 8.4 E | 6.8 E | 9.1 E | 11.9 E | 16.5 E | 21.1 E |
| 9 " | 12.3 E | 10.1 E | 7.8 E | 5.3 E | 7.2 E | 7.5 E | 10.7 E | 13.9 E |
| 10 " | 4.2 E | 4.2 E | 4.5 E | 3.5 E | 5.6 E | 5.5 E | 7.5 E | 9.5 E |
| 11 " | 4.0 W | 2.9 W | 1.9 W | 0.6 E | 1.9 E | 1.6 E | 1.1 E | 0.7 E |
| Noon | 9.9 W | 7.4 W | 5.0 W | 2.8 W | 2.2 W | 1.9 W | 4.2 W | 6.5 W |
| 1 p.m. | 6.6 W | 5.9 W | 5.5 W | 4.9 W | 6.0 W | 6.2 W | 7.2 W | 8.2 W |
| 2 " | 7.9 W | 6.6 W | 5.2 W | 3.5 W | 4.7 W | 5.5 W | 8.1 W | 10.7 W |
| 3 " | 8.7 W | 7.3 W | 6.1 W | 6.3 W | 7.7 W | 8.2 W | 10.4 W | 12.6 W |
| 4 " | 8.6 W | 6.7 W | 4.9 W | 5.1 W | 7.9 W | 8.9 W | 11.1 W | 13.3 W |
| 5 " | 9.2 W | 6.8 W | 4.2 W | 4.5 W | 8.1 W | 10.4 W | 13.3 W | 16.2 W |

The monthly mean values of the declination at Aklavik, as compared with the corresponding simultaneous values at Meanook communicated by Sir Frederic Stupart are given in the following table from which it appears that the annual inequality is very much greater at Aklavik than at Meanook, but the data are too few to justify any definite conclusions.

| | | Aklavik, N.W.T. | Meanook, Alta. |
|---|---|---|---|
| | | ° ′ | ° ′ |
| 1922 | Oct. | 44 23.7 E | 27 28.2 E |
| | Nov. | 16.8 | 26.9 |
| | Dec. | 16.4 | 25.5 |

| | | Aklavik, N.W.T. | | Meanook, Alta. | |
|---|---|---|---|---|---|
| | | ° | ′ | ° | ′ |
| 1923 | Jan. | 44 | 15.5 | 27 | 26.3 |
| | Feb. | | 8.2 | | 25.7 |
| | Mar. | | 3.6 | | 24.2 |
| | Apr. | | 10.5 | | 21.9 |
| | May | | 14.5 | | 20.6 |

Topographical Survey of Canada,
Department of the Interior,
May, 1924.

## NOTES AND QUERIES

**Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries**

### TWO CANADIAN APPOINTMENTS

Robert Meldrum Stewart has been appointed Director of the Dominion Observatory at Ottawa. Mr. Stewart is a graduate of the University of Toronto, having obtained the degree of B.A. in 1902 and of M.A. in 1903. Soon after this he was appointed to the newly organized observatory at Ottawa. One of his achievements there is a time service for the numerous government buildings of exceptional efficiency. He also established a meridian circle, with which much accurate work has been done. From it the accurate determinations of longitude and latitude throughout the country are controlled. In 1918 Mr. Stewart was made Assistant Director. In 1922 Dr. Klotz visited Europe, but the effort so impaired his health that he was able to be at the observatory only occasionally thereafter, and he died in December last. During his absence Mr. Stewart was Acting Director.

Reynold Kenneth Young has been appointed Associate Professor of Astronomy in the University of Toronto. He is a graduate of the University, being a B.A. of 1909. Immediately after receiving his degree he was made Fellow in the Lick Observatory, and after three years of training there and at Berkeley he received the Ph.D. degree from the University of California. He then spent a year at the University of Kansas as Instructor in Physics and Astronomy, and then was appointed to the observatory at Ottawa. In 1918 he went with Dr. Plaskett to be an astronomer in the Dominion Astrophysical Observatory at Victoria, B.C., and he has assisted to make the reputation of that institution throughout the world. His latest completed research was in collaboration with Mr. W. E. Harper and consisted in the determination of the parallax of over 1000 stars, an account of which appeared in this JOURNAL in the

first issue for 1924. Dr. Young and Mr. Stewart are both natives of Ontario.

BETELGEUZE

Miss Isabel M. Lewis in *Science Service* gives some interesting information regarding this wonderful star in Orion.

Betelgeuze is not only a giant, but is a most erratic giant. Later measurements with the interferometer show variations in its diameter such as have not been found in the measurements of the diameters of other giant stars with the same instrument. This fact taken in connection with the fact that Betelgeuze has long been known as a star that varies irregularly in brightness makes it appear that it is irregularly contracting and expanding in size, pulsating, like some mighty heart of the heavens. The brightness apparently increases with contraction and decreases with expansion of the star.

Betelgeuze is now at its maximum brightness. It is more brilliant than Rigel, the bluish-white star in Orion diagonally opposite to it, toward the southwest, and it has been rivalling and at times surpassing Capella, the beautiful golden star in Auriga to the northwest of it. It is also much brighter at the present time than it was a year ago. When at its maximum brightness Betelgeuze is over three and a half times more brilliant than it is at minimum brightness, and the change may take place within a year or less.

Aside from the fact that the diameter of the star is changing continually as a result of its irregular contraction and expansion, there is an additional uncertainty as to the actual size of Betelgeuze which results from the uncertainty as to its distance. To change the angular diameter, that is given by the interferometer, into miles it is necessary to know the parallax of the star which is simply the angular distance between earth and sun as viewed from the star. This value can be obtained in a variety of ways. According to the latest report from the Mt. Wilson Observatory, the best value of the parallax of Betelgeuze is 0".017. This is how far in angular measure the earth and sun would be at the distance of Betelgeuze. This value gives 190 light years as the distance of Betelgeuze from the earth and a diameter for the star of 245,000,000 miles.

Very recently the parallaxes of over one thousand stars have been determined at the Dominion Astrophysical Observatory at Victoria, B.C., with the 72-inch reflector by the spectroscopic method, and in this list we find for Betegeuze a parallax of 0".01, which would place Betegeuze at a distance of about 325 light years and give the star a diameter of over 400,000,000 miles. It is possible, then, that Betelgeuze may be even larger and more distant than earlier estimates have made it. It is probable that its size has been underestimated rather than overestimated and it may closely rival if not surpass Antares, which is estimated to have a diameter of about 400,000,000 miles.

With the value of the parallax found at the Dominion Astrophysical Observatory the actual brightness of Betelgeuze comes out about 5000 times that of the sun. If the sun and Betelgeuze were placed side by side at a distance of 33 light years from the earth the sun would appear as a faint star of the fifth magnitude but Betelgeuze would be as brilliant as Venus as it now appears in the western heavens.

## Ball Lightning

Mr. B. S. Wimbush, who has returned from Auckland, N.Z., to Garden Plain, Alberta, sends a note taken from *Scientific American* for April, 1924, referring to this interesting but mysterious phenomenon. Mr. Wimbush states that he has observed ball lightning himself.

In a recent address before the Institute of Electrical Engineers (British) Dr. G. C. Simpson discussed the question of "ball" or globular lightning. Dr. Simpson came to the conclusion, which is now very generally held, that this is a real natural phenomenon. He summed up the characteristics of ball lightning as follows: the body or ball itself, which is able to retain its individuality as it moves through the air, appears to be composed of gas or matter in some novel luminous condition. The balls appear to exist independently of any large electrical intensity, for they have been observed within closed rooms where large electrical fields are impossible, and have also been observed to pass in and out of parallel telegraph wires. They appear to be associated directly or indirectly with large quantities of energy, for they have been observed to explode with violence, and have also been seen to fuse the overhead wire of an electrical tramway.

No satisfactory explanation of ball lightning has, however, been offered. Dr. Russell says: "Globular lightning seems to be a brush discharge taking place at the end of a column of air of higher conductivity than the neighbouring air." He then points out some of the difficulties of this explanation, to which others can be added; in fact, there is really nothing very similar between a brush discharge and the ball of glowing gas so frequently described. The only physical phenomenon yet produced in a laboratory at all approaching ball lightning is the active nitrogen studied by Lord Rayleigh. In this case we have a mass of nitrogen subjected to an electrical discharge which continues to glow for some time after it has been removed from the field. Lord Rayleigh, however, is unable to accept this explanation of ball lightning, and all that we are able to say is that active nitrogen is the nearest physical phenomenon to ball lightning yet produced in our laboratories. Ball lightning appears always to be associated with a thunderstorm, and it is possible that the intense discharge of a lightning flash can produce some atomic change in the air or rain through which the discharge passes. If this is so, the glowing matter of ball lightning, which distinguishes it from others, may be in a state otherwise not met with in nature.

### *A Very Fine Rainbow*

On July 1, 1924, was celebrated the fifty-seventh anniversary of the union of the provinces of Canada into a Dominion, and the weather showed a great variety for the holiday. At Toronto and in Ontario generally the temperature was rather low for the time of the year while at Edmonton it rose to 96.

In the neighbourhood of Toronto there were several heavy showers with bright sunshine between. Hail also fell during the afternoon. But the brilliant portion of the performance occurred at about 5.30 p.m. (standard time) when, just as a smart shower was ending, a remarkably fine rainbow—or rather pair of rainbows —appeared in the east. The complete arcs could be seen from horizon to horizon and the space between them was exceptionally dark, a marked contrast to the segment within the primary bow. Also the supernumerary bows within the primary bow were particularly plain, being observed by many who had never heard of their existence. There were three of these bands—red, green, blue; red, green, blue; red— and they could be traced the entire length of the primary, not just at the upper portion where these extra bows are usually seen. C.A.C.

# MEETINGS OF THE SOCIETY

## At Victoria

January 24, 1924.—A regular meeting of the Society was held in the Auditorium of the Girls' Central School on the above date, at 8 p.m. The President, Mr. J. Duff, in the chair.

Mr. Hill was elected a member of the Society, and Dr. A. G. Price and Mr. S. L. Feesey were nominated for membership.

Mr. W. H. Christie gave an interesting discourse on the Handbook.

The lecture of the evening was then given by the President on the "Life of Copernicus".

The name of Copernicus is associated with the most revolutionary discovery ever made in astronomy. He overthrew a false, though plausible, theory of the universe, and set up in its place one that was essentially sound in its general outline.

Ptolemy in the second century had rejected the idea of a solar system held by Aristarchus, and had definitely adopted the geocentric arrangement, explaining the direct and retrograde motions of the planets by means of epicycles, or minor circles, carried around the circumference of large circles or orbits, with the earth as their common centre. Eccentrics accounted for inequalities of revolution in different parts of the large orbits. This Ptolemaic theory as set forth in the "Syntaxis" held the field undisputed for 1400 years.

Nicholas Kopernik, a Polish monk and physician, became interested in astronomy probably through the astrological side of his profession as it was then practised. Having heard of the views of Aristarchus, he set to work with very crude instruments to observe the motions of the planets. He tried the Ptolemaic system with many modifications, but found that it would not represent the observed motions accurately. Abandoning, then, the earth and taking the sun as the centre of motion, he found complexity and disorder replaced by simplicity and harmony. The earth took its place among the planets. It was a celestial body too; its rotation, not the revolution of an assumed *primum mobile*, caused the apparent diurnal motion of all the heavenly bodes, and the epicycles of the several planets were simply the reflection, as it were, of its annual revolution. Copernicus not unnaturally retained the conception of uniform circular motion and consequently had to retain some of Ptolemy's eccentrics.

With this great discovery, modern astronomy was started on its wonder-

ful career, and all branches of science and human thought received a great impulse from the shock to mere traditional authority, and the realization that there might still be wide fields for investigation.

After an interesting discussion a hearty vote of thanks was tendered the President for his interesting address and the meeting terminated.

February 21.—A joint meeting of the Society and the Vancouver Island Puspectors' Association was held on Thursday, February 21, at 8 p.m., in the Auditorium of the Girls' Central School. The President, Mr. J. Duff, presided.

The regular business of the Society was postponed to the next general meeting.

Dr. E. M. Burwash of the University of B.C. lectured on "The Planetesimal Hypothesis".

A brief resume of the historical conceptions of the cosmogony, including Egyptian, Hindu, Hebrew and Greek early ideas and later Graeco-Roman scientific development, followed by a reversion to older ideas during the reign of scholasticism in the Middle Ages and the great revival of the Renaissance, when Copernicus, followed by Newton and others, gave us the present completed conception of the solar system and enunciated its dynamic laws. This opened the way for the modern speculations as to the origin, history and future of the sun and its satellites, a phase of scientific development which is still in progress. Among others, Emmanuel Kant developed a theory of the origin of the solar system, but the gaseous nebula theory of Laplace held the field as against all others for over a century.

Geology at first accepted the Laplacian hypothesis and endeavoured to fit its geologic data into it, but as the observed data increased in number and were more thoroughly studied and related systematically, the Laplacian hypothesis became less and less satisfactory. In the nineties of the last century Professor T. C. Chamberlin of Chicago, in working out a theory of the causes of glacial periods, found the old hypothesis of the origin of the atmosphere unsatisfactory, and investigating it from the standpoint of the earth's parabolic velocity and the molecular velocities of heated gases such as the Laplacian theory demanded in the former, greater atmosphere of the earth, found that the theory seemed untenable. Calling in the aid of an astronomer, Prof. Moulton, the objections to the Laplacian hypothesis were soon multiplied in number, especially from the dynamic side, and a new hypothesis gradually took form. This theory, "The Planetesimal Hypothesis", holds that the earth and other planets have been formed not by the cooling and shrinking of great spheroids of heated gas, but by the infall of solid, liquid or gaseous particles on an original solid nucleus. These smaller particles or planetesimals were previously describing wide orbits, planet-like, around the central mass which later became the sun, and the type of celestial objects which correspond to such a system of larger nuclei and

smaller materials rotating in this fashion seems to be that class of objects which are known as spiral nebulae. The formation of such a spiral nebula from a star by the extremely violent tidal acton caused by the close approach of another star was briefly described by the lecturer, and the two-armed nebula thus produced was afterward followed through the process of the gradual ingathering of its materials by gravity around its various larger masses or nuclei, until the result was the development of the present solar system with its central sun, planets revolving nearly in one plane, and satellites revolving round the planets.

In closing, a few explanations were offered as to the greater competence of such a theory to explain the data as to the earth's structure and history which are furnished by the science of geology, rather than that of astronomy.

At the close of the lecture Dr. Plaskett referred to the influence of geology on astronomical views. Dr. Burwash replied to a number of queries.

F. MOORE, *Secretary.*

### At London

The regular April meeting was held in Room 4, University of Western Ontario, Dr. H. R. Kingston presiding.

Mr. E. H. McKone, B.A., gave an address on "Seasons on the Earth and on the other Planets". His address was illustrated by means of diagrams, a planetarium and other instruments. Mr. McKone pointed out that seasonal changes on the earth depend on the inclination of the plane of the earth's equator to the plane of its orbit, and, to a slight extent, on the eccentricity of the earth's orbit. He showed how the sun's rays strike the northern hemisphere more nearly perpendicularly in our summer than in our winter, thus causing an increase in the amount of heat received during the summer.

The lecturer then pointed out that Mercury's equatorial plane probably lies about exactly in the plane of its orbit so that from this source there is no cause of seasonal changes upon that planet. On the other hand Mercury's orbit about the sun is more elliptical than that of any other planet and causes Mercury to be only 2/3 as far from the sun at perihelion as it is at aphelion. It is uncertain how fast Mercury rotates on its axis but many astronomers believe it rotates once while it revolves once about the sun. Since Mercury possesses no atmosphere there will be no distribution of heat from one locality to another as there is on the earth.

In the case of Venus we find that its path around the sun is nearly a circle so that varying distance plays no part in temperature changes. Further, because of the white cloudy atmosphere that envelops the planet it has been difficulty to determine with certainty the plane of its equator or the length of its day.

Mars is much like the earth. Its equator is inclined to its orbit at almost exactly the same amount as in the case of the earth. Its orbit is more

elliptical than that of the earth so that Mars receives 1/3 more heat during its summer than during its winter. The variations in its seasons would therefore be somewhat greater than those on the earth and this would be accentuated by the very small amount of atmosphere present.

The lecturer pointed that Jupiter's equator lies almost exactly in the plane of its orbit and therefore the inclination factor is negligible in causing changes of seasons. Saturn's equator is inclined to its orbit at an angle greater than that in the case of the earth and therefore very marked seasonal changes would be experienced there. The orbits of both planets are sufficiently elliptical to cause the amount of heat received in summer to be 15 or 20% greater than in winter. Both planets are probably still in a gaseous state, so that the actual conditions there bear very little smilarity to those with which we are familiar on the earth. Because of their great distance from the sun they receive far less heat than the earth receives.

Very little is known about the conditions on Uranus and Neptune.

Mr. McKone's address was followed by a short informal discussion by Dr. Kingston of the atmospheres on the planets and the reasons why some planets, like Mercury and Mars, have lost all, or nearly all their atmospheric appendages, if they ever possessed any, and why other planets like Venus, the earth, Jupiter, and Saturn retain around them great gaseous envelopes. In the case of Mercury and Mars, the gravity in each case is so small that the molecules of gas readily escape from them.

An Observation Meeting was held on Wednesday, May 7th, at the Normal School. The meeting began at 4.45 p.m. in order to observe the transit of Mercury. Very successful observations were made. A screen, the work of Messrs. Benson and Rowley, was fitted to Mr. W. E. Saunders' large telescope and on this screen the image of the sun was projected. This enabled a large number to observe the transit at the same time.

After the observation of the transit refreshments were served in the Normal School under the management of Mrs. Saunders and her committee.

Because of unfavourable weather conditions after refreshments were served it was not possible to make further observations. Dr. Kingston therefore gave an informal talk, dealing with a number of problems connected with the transits of Mercury. By means of blackboard diagrams and a special bit of apparatus consisting of two planes inclined the one to the other, he explained clearly why the transits occur and also why they do not occur more frequently.

The meeting was well attended by the regular members of the society and the numbers were augmented by Dr. Kingston's Astronomy class. In spite of the cloudy weather later in the evening, the meeting was a successful one.

E. T. WHITE, *Secretary.*

### At Toronto

May 6.—The regular meeting of the Society was held in the Physics Building of the University at 8 p.m., the 2nd Vice-President, Mr. A. F. Hunter, in the chair.

The following were elected Members of the Society:—

Donald M. Grant, K.C., Huntsville, Ont.
George K. Deeprose, Morrin, Alta.
John Robertson, 53 Castlefrank Rd., Toronto.
Miss E. A. M. McConkey, 277 Russell Hill Road, Toronto.
Miss E. Cohen, 85 St. Clair Ave. East, Toronto.
Miss D. Longworthy, 2035 Hamilton St., Regina, Sask.
Mr. J. G. Mallon, 375 Brunswick Ave., Toronto.
Mr. L. C. Forster, 88 Gloucester St., Toronto.
Mr. F. G. Fitzgerald, 88 Gloucester St., Toronto.
Mr. E. Crozier, 276 Glenholme Ave., Toronto.
Mr. A. McFadden, 202 Geoffrey St., Toronto.
Mr. W.J.A. Hastie, 116 Glenmore Rd., Toronto.
Mr. F. H. Bonnell, Fernie, B.C.
Mr. C. T. Darke, Regina, Sask.
Mr. H. A. W. Plaxton, 66 Highlands Ave., Toronto.
Mr. J. A. Haines, 345 Spadina Rd., Toronto.
Mr. F. J. MacRae, 562 Crawford St., Toronto.
Mr. K. D. Haywood, 510 Jarvis St., Toronto.
Rev. Jno. F. H. Carr-Gregg, Astley Vicarage, Warwickshire, Eng.

The assistant Librarian reported 75 periodicals received during the month of April.

Mr. A. F. Miller gave observations which he had made on the visual binary system of Castor which led him to estimate the period of the system to be about 580 years.

The General Secretary, Mr. F. T. Stanford, addressed the meeting on "Means of advancing the interests of the Society". After referring to the position already reached by the Society, whose Journal is known both here and in foreign lands, he suggested means by which larger numbers of amateurs might yet be reached. One method suggested was—to have an organization to provide and control the use of small telescopes in the public parks, and another was to form a speakers' committee, which would arrange for addresses to be given to organizations requesting them.

The Recorder spoke on "The Nature of the Nebulae." This talk, which was illustrated by slides showing the various types of nebulae, was a synopsis of a lecture given in February by Prof. H. N. Russell, of Princeton Observatory.

H. F. BALMER, *Recorder.*

# The Royal Astronomical Society of Canada

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